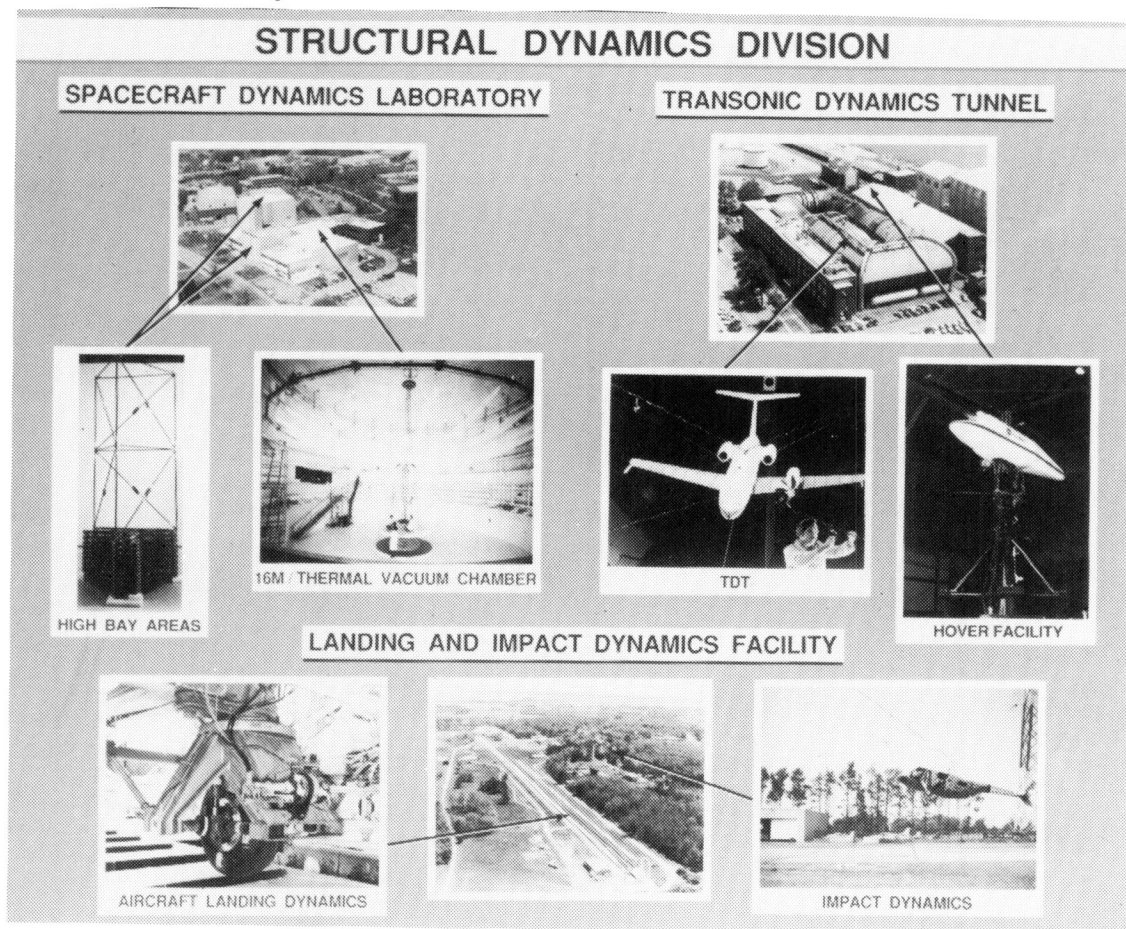


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STRUCTURAL DYNAMICS DIVISION RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR F.Y. 1991 AND PLANS FOR F.Y. 1992

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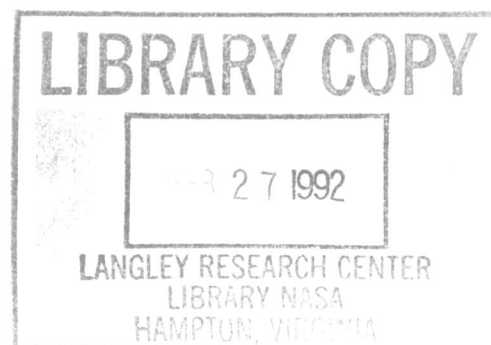


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STRUCTURAL DYNAMICS DIVISION
RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR F.Y. 1991
AND PLANS FOR F.Y. 1992

SUMMARY

The purpose of this paper is to present the Structural Dynamics Division's research accomplishments for F.Y. 1991 and research plans for F.Y. 1992. The work under each branch/office (technical area) is described in terms of highlights of accomplishments during the past year and plans for the current year as they relate to 5-year plans and the objectives for each technical area. This information will be useful in program coordination with other government organizations, universities, and industry in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized into directorates as shown in figure 1. Directorates are subdivided into divisions and offices. The Structural Dynamics Division of the Structures Directorate consists of five branches and one office as shown in figure 2. This figure lists the key people in the division which consists of 79 NASA civil servants and 13 members of the Army Aerostructures Directorate, USAARTA, Army Aviation Systems Command collocated at the Langley Research Center. Phone numbers for each organization are given. A recent change in a key position is the selection of Dr. Woodrow Whitlow as Head of the Unsteady Aerodynamics Branch. Each branch/office represents a technical area and focused activities under the technical areas are shown in the figure.

The Division conducts analytical and experimental research in six technical areas to meet technology requirements for advanced aerospace vehicles. The research thrusts are given in figure 3. The Configuration Aeroelasticity Branch (CAB), Unsteady Aerodynamics Branch (UAB), and Aeroservoelasticity Branch (ASEB) all work in the area of the prediction and control of aeroelastic stability and response of aircraft and rotorcraft. The Landing and Impact Dynamics Branch (LIDB) conducts research on the crash dynamics of aircraft structures and on the technology for improving the safety and handling performance of aircraft during ground operations. The Spacecraft Dynamics Branch (SDB) conducts research on the prediction and control of the structural dynamic response of complex space structures. The Interdisciplinary Research Office (IRO) develops methodology for aerospace vehicle design with emphasis on providing analytical methods to quantify interactions among engineering disciplines and to exploit this interaction for improved performance.

FUNCTIONAL STATEMENT

The Division conducts analytical and experimental research in the areas of configuration aeroelasticity, aeroservoelasticity, unsteady aerodynamics, impact and landing dynamics, spacecraft dynamics, and multidisciplinary design to meet technology requirements for advanced atmospheric and space flight vehicles. It also develops analytical and computational methods for predicting and controlling aeroelastic instabilities, deformations, vibrations, and dynamic response. The Structural Dynamics Division investigates the interaction of structure with aerodynamics and control systems, landing dynamics, impact dynamics, and resulting structural response. It evaluates structural configurations embodying new material systems and/or advanced design concepts for general application and for specific classes of new aerospace vehicles. The Division develops methodology for aircraft and spacecraft design using integrated multidisciplinary methods. A broad spectrum of test facilities to validate analytical and computational methods and advanced configuration and control concepts are used. Research techniques to demonstrate safety from aeroelastic instabilities for new airplanes, helicopters, and space launch vehicles are developed. Test facilities include the Transonic Dynamics Tunnel, the Helicopter Hover Facility, the Impact Dynamics Research Facility, the Aircraft Landing Dynamics Facility, the Space Structures Research Laboratory, and the Structural Dynamics Research Laboratory.

FACILITIES

The Structural Dynamics Division has four major facilities available to support its research as shown in figure 4.

The Transonic Dynamics Tunnel (TDT) is a maximum Mach 1.2 continuous flow, variable pressure wind tunnel with a 16-square-foot test section which normally uses air or a heavy gas (R-12) as the test medium. The maximum Reynolds number obtainable is approximately 10 million per foot in heavy gas and 3 million per foot in air. The TDT is a unique "National" facility that is used almost exclusively for testing of aeroelastic phenomena. Semi-span, sidewall mounted models and full-span sting mounted or cable-mounted models are used for aeroelastic studies of fixed wing aircraft. In addition, the Aeroelastic Rotor Experimental System (ARES) test stand is used in the tunnel to study the aeroelastic characteristics of rotor systems. The Helicopter Hover Facility (HHF), located in an adjacent building, is used to set up the ARES test stand in preparation for entry into the TDT and for rotorcraft studies in hover. The TDT Data Acquisition System is capable of simultaneous support of tunnel tests, HHF tests and model checkout in the Calibration Lab. A major facility upgrade to improve the heavy gas reclamation system is now in progress. The heavy gas reclamation system upgrade was completed in late December 1991 after which normal operations with both air and heavy gas will resume.

The Aircraft Landing Dynamics Facility (ALDF) is capable of testing various types of landing gear systems at velocities up to 200 knots on a variety of runway surfaces under many types of simulated weather conditions. The ALDF consists of a 2800-foot long rail system, a 2.0 million pound thrust propulsion system, a test carriage, and an arrestment system. Test articles can be subjected to vertical loads up to 65,000 pounds or sink rate of 20

feet per second on a wide variety of runway surface conditions. The facility provides for testing at speeds and sizes pertinent to large transport aircraft, fighter aircraft, and the Space Shuttle Orbiter.

The Impact Dynamics Research Facility (IDRF) is capable of crash testing full-scale general aviation aircraft and helicopters under controlled conditions. The facility is a 220-foot high, 400-foot long gantry structure which is the former Lunar Landing Facility. General aviation aircraft and helicopters weighing up to 20,000 pounds can be tested up to 60 mph using a free-swing pendulum approach. Attitudes can be adjusted for desired pitch, roll, and yaw parameters. Impact surfaces can be concrete or dirt. High-speed motion pictures and 90 data channels are available to record the crash event. A vertical test apparatus is attached to one leg of the facility for drop testing structural components. The facility is used to support in-house research and other agency programs (Army, Air Force, FAA).

The Structural Dynamics Research Laboratory (SDRL) is designed for conducting research experiments on the dynamics and control of flexible spacecraft structures. The facilities in this laboratory include the 16 meter Thermal Vacuum Chamber, the Main Backstop Area, and the Tower Test Area. These facilities provide a variety of environmental simulation capabilities, including acceleration, vacuum and thermal radiation. The chamber has a 55-foot diameter, hemispherical dome with a 64-foot high peak, flat floor and option for a large centrifuge or a rotating platform. Access is by an airlock door and an 18 x 20-foot test specimen door. A vacuum level of 10 torr can be achieved within 120 minutes and, with diffusion pumps, 10^{-4} torr vacuum can be achieved within 160 minutes. A temperature variation of 100°F can be obtained in the chamber by using 250 square feet of portable radiant heaters and liquid nitrogen cooled-plates. The Backstop Area is dominated by the 38-foot high backstop of I-beam construction. Test areas around this fixture are 15 x 35 x 38 feet high and a tower 12 x 12 x 95 feet high, both equipped with hydraulic and pneumatic supply lines. There are various sizes of hoists and accessible platforms for suspension system attachment, instrumentation installation, and test viewing. Closed-circuit television is available for monitoring research studies. Test articles can be excited by several types of actuators and small shakers. State-of-the-art capability is available for signal conditioning and data processing.

The Space Structures Research Laboratory (SSRL) is a large open room of dimensions 75 x 84 x 67 feet high. It has a truss framework spanning most of the ceiling area from which lightweight test articles can be supported. A hoist having a capability of approximately 2 tons is available. Access is through a 12 x 12-foot door. A 10 x 10-foot backstop is available in one corner. A control room equipped for structural and structural dynamics data acquisition and analysis equipment is available. Test equipment such as electromagnetic shakers, sensors, and signal conditioning equipment is shared with the SDRL and similar closed-circuit test monitoring and support are available.

F.Y. 1991 ACCOMPLISHMENTS

Configuration Aeroelasticity Branch

The Configuration Aeroelasticity Branch conducts research (fig. 5) to develop the aeroelastic understanding and prediction capabilities to apply new aerodynamic and structural concepts to future flight vehicles and to determine and to solve the aeroelastic problems of current designs as well as to evaluate the aeroelastic characteristics of new rotor systems. Present activities and future plans for the major activity areas are presented in figure 6.

The Configuration Aeroelasticity F.Y. 1991 accomplishments listed below are highlighted in figures 7 through 16.

Aircraft Aeroelasticity:

- Multiple Function Active Controls System Demonstrated in TDT
- Flutter of All-Movable NASP-Like Wings Investigated for Model Testing in Hypersonic Helium Tunnel

Benchmark Models:

- Comprehensive Benchmark Models Program NACA 0012 Model Test Conducted in TDT
- Benchmark Supercritical Wing Ready for Testing in TDT

Rotorcraft Aeroelasticity:

- Capabilities of Modified ARES Test Bed Demonstrated in TDT
- Parametric Bearingless Hub (PBH) Being Developed for TDT Testing
- Rotorcraft Optimization Validation at the Transonic Dynamics Tunnel in Progress

TDT Facility Operations:

- Modifications Completed for The Transonic Dynamics Tunnel Heavy Gas Reclamation System
- Hardware Improvements Implemented for The Transonic Dynamics Tunnel Data Acquisition System
- A Subcritical Response Technique Implemented on the MODCOMP Data Acquisition System at TDT

Unsteady Aerodynamics Branch

The Unsteady Aerodynamics Branch (UAB) conducts research (fig. 17) to develop, validate, and apply a set of Computational Fluid Dynamics (CFD) methods for predicting steady and unsteady aerodynamic airloads and the aeroelastic characteristics of flight vehicles. The branch also supports research activities aimed at the generation of experimental data bases needed for computer code validation. Current research topics reflect a major emphasis on accurately predicting transonic aeroelastic phenomena, such as wing "flutter-speed dip" and aileron "buzz." Recently, research topics such as dynamic

vortex-structure interactions, dynamic loads, and buffet prediction have also become important areas of investigation within the UAB. Interest in these latter topics is due to the emerging importance of the high angle-of-attack maneuvering flight capabilities demonstrated by a number of current high performance aircraft. A computational methodology which can be used to accurately and efficiently predict this wide range of unsteady aerodynamic and aeroelastic phenomena should be based upon a number of different CFD mathematical formulations. The CFD methods developed within the UAB include Transonic Small Disturbance methods, Euler equation methods, and Reynolds-averaged Navier-Stokes based techniques. The branch research program is outlined in figure 18 which shows the 5-year plan for the development of aerodynamic analysis methods and aeroelastic prediction techniques. The plan also provides the UAB participation in the Structural Dynamics Division's Benchmark Models Program (BMP). This experimental effort includes participation in both the TDT wind tunnel tests, as well as pretest and post-test CFD analysis activities.

The Unsteady Aerodynamics F.Y. 1991 accomplishments listed below are highlighted in figures 19 through 24.

Transonic Small Disturbance CFD Methods:

- CAP-TSD Extended to Treat Flexible Vertical Surface Configurations
- Improved Transonic Flutter Prediction of AFW Wind Tunnel Model
- Strip Boundary Layer Improves Steady and Unsteady CAP-TSD Results
- Effects of Airfoil Pitch Oscillation Frequency in Transonic Small Disturbance Theory Calculations

Euler/Navier-Stokes CFD Methods:

- Implicit Upwind Euler Algorithm Based on Unstructured Dynamic Meshes Demonstrated for Complex Aircraft Configuration
- Spatial Adaptation Procedure Verified for Unsteady Airfoil Analysis

Aeroservoelasticity Branch

The Aeroservoelasticity Branch (fig. 25) conducts research to enhance/develop: modeling and analysis methods for accurately determining the aeroelastic characteristics of flexible vehicles in all flight regimes including controlled aircraft undergoing severe thermal changes; advanced algorithms for designing control systems to prevent undesirable structural and aeroelastic response; methodologies for integrating structures, aerodynamics, and controls disciplines into an aeroservoelastic preliminary design capability; advanced concepts employing adaptive materials or unconventional control surfaces for alleviating aeroelastic response; and advanced finite element, structural optimization, aeroelastic tailoring, and aeroelastic stability methods for reducing rotorcraft vibrations. In addition, the branch performs wind tunnel experiments for obtaining data to validate the new and improved methodologies and provides technical support for NASA and DOD projects to insure that the flight envelope of the vehicle is free of unstable aeroelastic phenomena or adverse structural response. The scope of this work is more explicitly identified in figure 26 which shows the branch's 5-year plan.

The Aeroservoelasticity Branch F.Y. 1991 accomplishments listed below are highlighted by figures 27 through 42.

Design Methodology:

- Capability Developed for Basic Aeroelastic Analyses and Support of Design Optimization
- Two Schemes for Determining Maximum Gust Loads for Aircraft with Nonlinear Controls Demonstrated
- Time Simulation of Flutter with Large, Rapid Stiffness Changes
- Control Effectiveness Limit Defined for Piezoelectric Actuators on Full-Scale Aircraft
- Wing Loads Actively Controlled During Rolling Maneuvers
- Multiple Flutter Modes Suppressed Using Reduced Order LQG Control Law in AFW Wind Tunnel Test
- Flutter Suppression Using Piezoelectric Actuation Demonstrated in the Wind Tunnel
- Advanced Control Law Designs Used to Successfully Damp Structural Response

Analysis Methodology and Applications:

- Cooperative AFW Program Successfully Completed
- Multi-Input/Multi-Output Digital Controller Allows Multifunction Active Control of Aeroelastic Response
- Open-Loop Flutter Characteristics Determined From Closed-Loop Data
- Flutter Characteristics of Generic Hypersonic Vehicle Analyzed with Aeroelastic Vehicle Analysis (AVA) Codes
- Surface Heating Characteristics of a Generic Hypersonic Vehicle Predicted
- Nonlinear Aerodynamic Loads Calculated on Generic Hypersonic Vehicle

Rotorcraft Structural Dynamics:

- Parameters for Improving Tiltrotor Aeroelastic Stability in High-Speed Axial Flight Identified
- Geometric Entities Identified for Use with P-Version Finite Element Analyses

Landing and Impact Dynamics Branch

The Landing and Impact Dynamics Branch (fig. 43) operates two major facilities, the Aircraft Landing Dynamics Facility (ALDF) for experimental studies of aircraft landing gear systems and components and the Impact Dynamics Research Facility (IDRF) for experimental investigations of the crash response characteristics of metal and composite airframe structures. The landing dynamics group is responsible for research activities aimed at improving the technology needed to assure safe, economical all-weather ground operations and the development of new landing gear systems and concepts. The group coordinates in-house research, grant activities, contract efforts, and joint government-industry programs to achieve the required technology. The impact dynamics group conducts research to obtain a better understanding of the response characteristics of composite airframe components subjected to crash loads and to develop and enhance analytical tools for predicting these response characteristics and for providing insights into the fundamental physics associated with the structural behavior of these airframe components. In-house research, grant efforts, and contract activities are utilized to develop structural concepts that exhibit superior energy

absorption characteristics that result in reduced crash loads and to develop the technology needed to analyze these structural responses. The work of the Landing and Impact Dynamics Branch is more clearly identified in figure 44 which shows the 5-year plans for the disciplines in both landing and impact dynamics along with their expected results.

The Landing and Impact Dynamics Branch F.Y. 1991 accomplishments are highlighted in figures 45 to 54.

Impact Dynamics:

- Compression Testing Indicates that Crushing Behavior of Kevlar/Gr-Ep Hybrid Composite Plates is Independent of Trigger Mechanism Geometry
- Scaling of Energy Absorbing Composite Plates Demonstrated Through Compressive Testing
- Strength Scaling of $\pm 45^\circ$ Angle Ply Laminates Identifies Need for More Precise Specifications in ASTM Testing Standards
- Reduced Basis Technique Developed for Predicting the Nonlinear Vibrational Response of Composite Structures
- Macintosh-Based DAS Provides for Quick Analysis of Aircraft Crash Data
- Air Force F-111 Recovery Parachute Modification Program Supported by Testing at the Impact Dynamics Research Facility

Landing Dynamics:

- Effects of Yaw Angle and Vertical Load on Cornering Performance for 26 X 6.6 Bias-Ply and Radial-Belted Tires on a Wet Surface
- LaRC Tests Demonstrate Superior Wear Performance of Modified Space Shuttle Main Gear Tire
- National Tire Modeling Code (TIRE-3D) Distributed to Industry
- Accurate Sensitivity Derivatives for Shuttle Nose Gear Tire Obtained by Reduced Basis Technique

Spacecraft Dynamics Branch

The Spacecraft Dynamics Branch (fig. 55) conducts research and focused technology studies on the dynamics and control of flexible spacecraft. Analysis and prediction methods are developed for application to such spacecraft as Space Station Freedom, Earth-observing science platforms, and Solar System exploration spacecraft. Methods are verified and improved through experiments on research hardware. Advanced test and data analysis methods for improving the accuracy and speed of ground tests to simulate on-orbit behavior and/or to verify spacecraft and spacecraft components for flight are also developed. Significant ongoing emphasis is on interdisciplinary experiments on the control of flexible spacecraft, scale models for spacecraft development, and advanced algorithms for system identification. On-orbit verification methods and experiments are a long-term goal. The scope of this work is more explicitly identified in figure 56 which shows the 5-year plan of the organization's major thrusts and their expected result.

The Spacecraft Dynamics Branch F.Y. 1991 accomplishments listed below are highlighted in figures 57 through 68.

Controls-Structures Interaction:

- Phase-Zero CSI Evolutionary Model Tests Complete
- JPL-LaRC CEM Piezo Strut Tests
- CSI Computer System (CCS)/Remote Interface Unit (RIU) Acceptance Testing
- Hubble Space Telescope Solar Array Vibration Parameters Identified From Flight Data
- Space Shuttle RMS Active Damping Feasibility Determined

Dynamic Scale Model Technology:

- DSMT Analysis Model Updated Via Inclusion of Test Verified Component Models
- Dynamic Performance of Zero-Spring Rate Mechanism (ZSRM) Validated
- Refined Flexible Solar Arrays Developed for DSMT Model
- Module Cluster Assembled for DSMT Hybrid-Scale Model

Space Station Freedom - Modal Identification Experiment:

- Robust Alpha-Joint Controller Design Accommodates Large Structural Parameter Estimation Error
- MIE Simulations Validated by Generic Model Tests

Base Research:

- Short Record Multi-Input/Multi-Output System Identification Technique Developed and Validated

Interdisciplinary Research Office

The Interdisciplinary Research Office (fig. 69) conducts research aimed at the development, validation, and application of analytical methods for aerospace vehicle design wherein the interactions among all appropriate disciplines are accounted for and exploited. The research program includes the areas of optimization methods, sensitivity analysis, approximate and design-oriented analysis, proper accounting for discipline coupling in analysis and design, strategies for decomposing large complex problems into manageable subproblems, and applications to problems of agency interest. Current application areas include high-speed aircraft, rotorcraft, and controls-structure integrated design of spacecraft. The 5-year plan for the research program shown in figure 70 indicates the current activities and their goals.

The Interdisciplinary Research Office F.Y. 1991 accomplishments listed below are highlighted in figures 71 through 77.

Optimization Methods:

- Method for Tuning Mass Placement Reduces Helicopter Rotor Blade Vibration and Compares with Test Data
- Fully Integrated Aerodynamic/Dynamic Optimization Procedure for Helicopter Rotor Blades Demonstrated
- HiSAIR/Pathfinder Generates Minimum Weight Designs for Mach 3 Transport Configuration

Strategies for Decomposing Large Complex Problems:

- System Synthesis by Concurrent Suboptimizations Demonstrated for Control-Augmented Structure

Space Application:

- New Method Controls Thermal Distortion of Space Antennas

Discipline Coupling in Analysis and Design:

- Integrated Optimization Allows Favorable Trade of Structural Mass for Control Effort

Approximate and Design-Oriented Analysis:

- Sensitivity-Based Scaling for Approximating Structural Response

PUBLICATIONS

The F.Y. 1991 accomplishments of the Structural Dynamics Division resulted in a number of publications. The publications are listed below by organization in the categories of journal publications, formal NASA reports, conference presentations, contractor reports, technical briefs, and patents.

Division Office

Formal NASA Reports:

1. Doggett, R. V., Jr.: Some Observations on the Houbolt-Rainey and Peak-Hold Methods of Flutter Onset Prediction. NASA TM-102745, November 1990, 11 p.
2. Doggett, R. V., Jr.; Ricketts, R. H.; Noll, T. E.; Malone, J. B.: NASP Aeroservoelastoclastic Studies. NASA TM-104058, April 1991, 25 p.
3. Wynne, Eleanor C.: Structural Dynamics Division Research and Technology Accomplishments for F.Y. 1990 and Plans for F.Y. 1991. NASA TM-102770, January 1991, 228 p.

Configuration Aeroelasticity Branch

Formal NASA Reports:

4. Byrdsong, T. A.; Adams, R. R.; Sandford, M. C.: Close-Range Photogrammetry Measurement of Static Deflections for an Aeroelastic Supercritical Wing. NASA TM-4194, December 1990, 93 p.
5. Byrdsong, T. A.; Adams, R. R.; Sandford, M. C.: Close-Range Photogrammetry Measurement of Static Deflections for an Aeroelastic Supercritical Wing. Supplement to NASA TM-4194, December 1990, 265 p.
6. Keller, D. F.; Bullock, E. P.: Span Reduction Effects on Flutter Characteristics of Arrow-Wing Supersonic Transport Configurations. NASA TP-3077, May 1991, 53 p.
7. Keller, D. F.; Sandford, M. C.; Pinkerton, T. L.: Planform Curvature Effects on Flutter Characteristics of a Wing With 56° Leading-Edge Sweep and Panel Aspect Ratio of 1.14. NASA TP-3116, September 1991, 44 p.
8. Mirick, P. H.; Hamouda, M-N. H.; Yeager, W. T., Jr.: Wind-Tunnel Survey of an Oscillating Flow Field for Application to Model Helicopter Rotor Testing. NASA TM-4224, AVSCOM TR-90-B-007, December 1990, 35 p.
9. Yeager, W. T., Jr.; Hamouda, M-N.; Idol, R. F.; Mirick, P. H.; Singleton, J. D.; Wilbur, M. L.: Vibratory Loads Data From a Wind-Tunnel Test of Structurally Tailored Model

Helicopter Rotors. NASA TM-4265. Also available as AVSCOM TR-91- B-001, August 1991, 118 p.

Conference Presentations:

10. Cole, S. R.; Henning, T. L.: Dynamic Response of a Hammerhead Launch Vehicle Wind-Tunnel Model. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1050-CP. In Proceedings, Part 3, pp. 1751-1760. Also available as NASA TM-104050, February 1991, 11 p.
11. Durham, M. H.; Keller, D. F.; Bennett, R. M.; Wieseman, C. D.: A Status Report on a Model for Benchmark Active Controls Testing. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper. No. 91-1011-CP. In Proceedings, Part 1, pp. 704-709.
12. Moss, S. W.; Cole, S. R.; Doggett, R. V., Jr.: Some Subsonic and Transonic Buffet Characteristics of the Twin-Vertical-Tails of a Fighter Airplane Configuration. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1049-CP. In Proceedings, Part 3, pp. 1742-1750.
13. Rivera, J. A., Jr.; Dansberry, B. E.; Farmer, M. G.; Eckstrom, C. V.; Seidel, D. A.; Bennett, R. M.: Experimental Flutter Boundaries With Unsteady Pressure Distributions for the NACA 0012 Benchmark Model. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1010-CP. In Proceedings, Part 1, pp. 697-703. Also available as NASA TM-104072, July 1991, 8 p.
14. Wilbur, M. L.: Experimental Investigation of Helicopter Vibration Reduction Using Rotor Blade Aeroelastic Tailoring. Presented at the American Helicopter Society 47th Annual Forum and Technology Display, May 6-8, 1991, Phoenix, AZ. In Proceedings Vol. 2, pp. 969-983.
15. Yeager, W. T., Jr.; Mirick, P. H.; Hamouda, M-N. H.; Wilbur, M. L.; Singleton, J. D.; Wilkie, W. K.: Recent Rotorcraft Aeroelastic Testing in the Langley Transonic Dynamics Tunnel. Presented at the American Helicopter Society 47th Annual Forum and Technology Display, May 6-8, 1991, Phoenix, AZ. In Proceedings, Vol. 1, pp. 687-703.

Unsteady Aerodynamics Branch

Journal Publications:

16. Batina, J. T.: Unsteady Euler Algorithm With Unstructured Dynamic Mesh for Complex-Aircraft Aeroelastic Analysis. AIAA Journal, Vol. 29, No. 3, March 1991, pp. 327-333.

17. Batina, J. T.: Vortex-Dominated Conical-Flow Computations Using Unstructured Adaptively-Refined Meshes. AIAA Journal, Vol. 28, No. 11, November 1990, pp. 1925-1932.
18. Bennett, R. M.; Bland, S. R.; Batina, J. T.; Gibbons, M. D.; Mabey, D. G.: Calculation of Steady and Unsteady Pressures on Wings at Supersonic Speeds With a Transonic Small-Disturbance Code. Journal of Aircraft, Vol. 28, No. 3, March 1991, pp. 175-180.
- 19.. Lee, E. M.; Batina, J. T.: Conical Euler Simulation of Wing Rock for a Delta Wing Planform. Journal of Aircraft, Vol. 28, No. 1, January 1991, pp. 94-96.
20. Malone, J. B.; Narramore, J. C.; Sankar, L. N.: Airfoil Design Method Using the Navier-Stokes Equations. Journal of Aircraft, Vol. 28, No. 3, March 1991, pp. 216-224

Formal NASA Reports:

21. Batina, J. T.: Development of Unstructured Grid Methods for Steady and Unsteady Aerodynamic Analysis. NASA TM-102730, November 1990, 12 p.
22. Batina, J. T.: Implicit Flux-Split Euler Schemes for Unsteady Aerodynamic Analysis Involving Unstructured Dynamic Meshes. NASA TM-102732, November 1990, 10 p.
23. Batina, J. T.: Three-Dimensional Flux-Split Euler Schemes Involving Unstructured Dynamic Meshes. NASA TM-102731, November 1990, 8 p.
24. Batina, J. T.; Lee, E. M.; Kleb, W. L.; and Rausch, R. D.: Unstructured-Grid Methods Development for Unsteady Aerodynamic and Aeroelastic Analyses. NASA TM-104143, September 1991, 10 p.
25. Bland, S. R.: Suggestions for CAP-TSD Mesh and Time-Step Input Parameters. NASA TM-104083, June 1991, 23 p.
26. Kleb, W. L.; Batina, J. T.; Williams, M. H.: Temporal-Adaptive Euler/Navier-Stokes Algorithm for Unsteady Aerodynamic Analysis of Airfoils Using Unstructured Dynamic Meshes. NASA TM-102734, November 1990, 9 p.
27. Robinson, B. A.; Batina, J. T.; Yang, H. T. Y.: Aeroelastic Analysis of Wings Using the Euler Equations With a Deforming Mesh. NASA TM-102733, November 1990, 10 p.
28. Woolley, C. L.; Batina, J. T.: User's Guide to a System of Finite-Element Supersonic Panel Flutter Programs. NASA TM-104109, July 1991, 53 p.

Conference Presentations:

29. Batina, J. T.: Unstructured-Grid Methods Development - Lessons Learned. Presented at the Fourth International Symposium on Computational Fluid Dynamics, September 9-12, 1991, Davis, CA. Also available as NASA TM-104137, August 1991, 7 p.

30. Batina, J. T.: Unstructured-Grid Methods Development for Unsteady Aerodynamic Analysis. Presented at the NASA Computational Fluid Dynamics Conference, March 12-14, 1991, Moffett Field, CA. In CFD Compendium of Abstracts, pp. 10-11.
31. Bennett, R. M.; Dansberry, B. E.; Farmer, M. G.; Eckstrom, C. V.; Seidel, D. A.; Rivera, J. A., Jr.: Transonic Shock-Induced Dynamics of a Flexible Wing With a Thick Circular-Arc Airfoil. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1107-CP. In Proceedings, Part 3, pp. 1919-1928. Also available as NASA TM-104088, May 1991, 11 p.
32. Bennett, R. M.; Dansberry, B. E.; Farmer, M. G.; Eckstrom, C. V.; Seidel, D. A.; Rivera, J. A., Jr.: Shock-Induced Dynamics of a Flexible Wing With a Thick Circular-Arc Airfoil at Transonic Speeds. Presented at the International Forum on Aeroelasticity and Structural Dynamics, June 3-6, 1991, Aachen, Germany, Paper No. 91-127.
33. Lee, E. M.; Batina, J. T.: Conical Euler Methodology for Unsteady Vortical Flows About Rolling Delta Wings. Presented at the AIAA 29th Aerospace Sciences Meeting and Exhibit, January 7-10, 1991, Reno, NV. AIAA Paper No. 91-0730.
34. Rausch, R. D.; Batina, J. T.; Yang, H. T. Y.: Spatial Adaption Procedures on Unstructured Meshes for Accurate Unsteady Aerodynamic Flow Computation. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1106-CP. In Proceedings, Part 3, pp. 1904-1918. Also available as NASA TM-104039, March 1991, 16 p.
35. Silva, W. A.: A Methodology for Using Nonlinear Aerodynamics in Aeroservoelastic Analysis and Design. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1110-CP. In Proceedings, Part 3, pp. 1951-1963. Also available as NASA TM-104087, May 1991, 14 p.

Aeroservoelasticity Branch

Journal Publications:

36. Pototzky, A. S.; Zeiler, T. A.; Perry, B., III: Calculating Time-Related Gust Loads Using Matched Filter and Random Process Theories. Journal of Aircraft, Vol. 28, No. 5, May 1991, pp. 346-352.

Formal NASA Reports:

37. Hinnant, H. E.: Improved Finite-Element Methods for Rotorcraft Structures. NASA TM-104104, AVSCOM TR-91-B-006, August 1991, 26 p.

38. Karpel, M.; Hoadley, S. T.: Physically Weighted Approximations of Unsteady Aerodynamic Forces Using the Minimum-State Method. NASA TP-3025, March 1991, 45 p.

Conference Presentations:

39. Bohlmann, J. D.; Scott, R. C.: A Taguchi Study of the Aeroelastic Tailoring Design Process. Presented at the AIAA/ASME/ASCE/AHS/ASC 32nd Structures, Structural Dynamics, and Materials Conference, April 8-10, 1991, Baltimore, MD. AIAA Paper No. 91-1041-CP. In Proceedings, Part 1, pp. 364-372.
40. Buttrill, C.; Bacon, B.; Heeg, J.; Houck, J.; Wood, D.: Simulation and Model Reduction for the AFW Program. Presented at the Flight Simulation Technologies Conference, New Orleans, LA, August 1991. Paper No. 91-2935.
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F.Y. 1992 PLANS

The F.Y. 1992 plans for the Structural Dynamics Division are broken out by each of the branches (technical areas) and selected highlights of proposed F.Y. 1992 milestones are presented.

Configuration Aeroelasticity Branch

CAB figure 78 summarizes accomplishments planned for F.Y. 1992 selected from the Branch's broad based research program on dynamic and aeroelastic phenomena of aircraft and rotorcraft. A large portion of this work is associated with wind tunnel tests in the Langley TDT with companion theoretical studies. Research studies are planned for both rotorcraft and aircraft.

Testing related to aircraft aeroelasticity will include two joint studies with the Boeing Commercial Aircraft Company. The first involves a test of a transport type wing model to investigate phenomena which cause limit cycle oscillations (LCO). The second study is a flutter evaluation of the new 777 aircraft with a model to be tested in TDT. A cooperative effort is also underway with Cessna to study in the TDT the flutter characteristics of a Citation X wing flutter model.

As part of the Benchmark Models Program a series of four instrumented rigid rectangular wing models have been designed and fabricated. These rigid models are designed for testing on a flexible mount system with pitch and plunge degrees of freedom. The first model, with a NACA 0012 airfoil, has successfully completed its second tunnel test with data reduction and formal documentation of results now underway. The second model in this series has a supercritical airfoil designated SC(2)-0414. This model is currently in the tunnel undergoing final preparations for testing. Fabrication of the third model in the series, with a 64A010 airfoil, is nearing completion with instrumentation to follow. All three of these models have two chords of unsteady pressure instrumentation totaling 80 transducers. The fourth model in the series is similar to the NACA 0012 model but with the addition of an active trailing edge control surface plus upper and lower surface spoilers. A new initiative for this year is to design and fabricate a flexible High-Speed Civil Transport (HSCT) model.

The rotorcraft aeroelasticity work will include testing of a BERP-type rotor using the Aeroelastic Rotor Experimental System (ARES) test bed. An automatic control concept for the ARES will also be evaluated during these tests. Development of the ARES 1.5 and ARES 2 test beds will continue with initial testing of the ARES 2 to take place in the Helicopter Hover Facility. Design work will continue for both a rotating balance for the ARES testbeds and a third-generation hingeless rotor hub (AHRO-III). Fabrication and initial testing of a Parametric Bearingless Hub (PBH) will be completed. Fabrication will begin on the initial set of optimized blades as part of the Langley rotorcraft optimization/validation effort.

Highlights of proposed F.Y. 1992 research for the three technical areas of Aircraft Aeroelasticity, Benchmark Models, and Rotorcraft Aeroelasticity are shown in CAB figures 79 through 81.

Unsteady Aerodynamics Branch

The F.Y. 1992 plans for the Unsteady Aerodynamics Branch are outlined in figure 82. There will be continued applications of the CAP-TSD code to aeroelastic response problems in order to further define its range of accuracy. As part of this activity, the branch will continue to provide support for the CAP-TSD code via a contract programmer. In addition, unsteady aerodynamic and aeroelastic response calculations will be performed using higher-order methods, such as solution procedures based on the Euler and Navier-Stokes equations. Correlations of computed results from UAB developed Euler/Navier-Stokes codes with other theoretical solutions and experimental data will help to evaluate and validate the new CFD methods. This year will also see new developments in the prediction of vortex and viscous dominated flows and their roles in aeroelastic response phenomena. These research efforts with higher-order CFD methods will be carried out using both structured and unstructured grid flow solvers. Finally, a further effort will be directed toward the development of an in-house capability to generate computational grids for use with both structured and unstructured grid CFD procedures.

Aeroservoelasticity Branch

Figure 83 lists the major tasks being pursued by the Aeroservoelasticity Branch in F.Y. 1992. In the Design Methodology area, activities to design multirate, multifunction digital control laws for alleviating undesirable aeroelastic response using advanced algorithms and unconventional control surfaces will be pursued. Plans are to test these concepts on the Benchmark Controls Model in F.Y. 1993. The development of an integrated multidisciplinary design methodology (HiSAIR, High-Speed Airframe Integration Research Project) is continuing. The branch objectives in this effort are to include aeroelasticity and ASE in the preliminary design activity of flight vehicles. Investigations will continue in extending adaptive materials technology for aeroelastic and ASE applications, and will emphasize modeling, analysis, and testing aspects. In the Analysis Methodology and Applications area, the focus of attention involves the development of procedures using nonlinear transonic aerodynamics to improve ASE analysis and design methodologies. Studies to enhance the aeroservoelastothermoelastic procedures and assess the effects of high temperatures and thermal gradients on the aeroelastic and ASE characteristics of a hypersonic vehicle will continue. Activities to develop a simulation laboratory for evaluating, in near-real time, the characteristics of advanced control law designs, as well as, the functionality of the branch's digital controller prior to wind tunnel testing will continue. In addition, the Matched Filter Theory approach for predicting maximized and time-correlated gust loads for aircraft structural design purposes will be applied to a realistic aircraft with nonlinear control system characteristics.

Selected highlights of ongoing F.Y. 1992 research are shown in figures 84 through 88.

Landing and Impact Dynamics Branch

During F.Y. 1992 a major focused technology activity in the area of landing dynamics will be the development of advanced active control landing gear concepts for HSCT applications. Components of this activity include in-house research on a smart orifice

concept using F-106 landing gear hardware, a grant activity to study the characteristics of electrorheological fluids for possible applications to active control landing gear technology, and a contract activity to develop analysis tools for active control landing gear studies. The smooth runway testing of the Surface Traction and Radial Tire (START) Program will be completed this year following tests with a wide-body main-gear tire and rolling tire footprint force measurements on three tire sizes. The branch tire modeling activities will continue with the development of second-order sensitivity derivatives for tire design and analysis and the initiation of a comprehensive program to develop tire/pavement friction prediction models. The ALDF will be down for approximately 6 months while the propulsion system valve body is replaced and a second high-pressure water pump is installed. The installation of the second water pump should enhance the productivity of the facility significantly. Figure 89 (a) lists the areas of continuing research activities in landing dynamics for F.Y. 1992.

The major focused technology activity in the impact dynamics area is associated with the Advanced Composite Technology (ACT) Program. In this area a task assignment contract will be awarded to fabricate test specimens for nondestructive and crash tests. Fabrication of a composite subfloor for a previously acquired Lear Fan full-scale crash test specimen will be completed in F.Y. 1992 so that a crash test can be conducted in F.Y. 1993. Strength scaling studies of composite structures under compressive loads to define failure mechanisms and the static and dynamic tests to determine the effects of floor location on composite fuselage frame crash responses will be completed this year. An in-house study of coherent, crushable fuselage frame concepts and a grant effort to study for optimizing composite frames for crash loads will be initiated this year. The evaluation of the MSC/DYNA code for crash dynamics analyses will be completed in F.Y. 1992 and the development of computationally efficient algorithms for composite structural analysis will continue. Figure 89 (b) lists the areas of continuing research activities in impact dynamics for F.Y. 1992.

Spacecraft Dynamics Branch

For F.Y. 1992, the Spacecraft Dynamics Branch will conduct focused technology development and base research along three lines (fig. 90.). In the focus technology area of Controls-Structures Interaction (CSI), the CSI Phase-1 Evolutionary Model will be installed in the Space Structures Research Laboratory and used to validate integrated controls-structure design methods. The Phase-1 Model is the same geometric configuration as the Phase-0 Model, but has component strut members sized to improve the line-of-sight control system performance. Following Phase-1 testing, the model will be evolved to a Phase-2 configuration by addition of gimballed payload simulators. The Phase-2 testbed will be used for multi-payload control and control architecture studies. For the Mission Dynamics focus technology area, the use of dynamically scaled structural models of large spacecraft will be further developed. Component and subsystem modal test data for the erectable truss model will be used to validate component mode synthesis analysis methods. Scale model redesign studies will be initiated to reflect the actual Space Station Freedom structural change from an erectable truss to a pre-integrated truss. For the Modal Identification Experiment on Space Station Freedom, the impact of SSF structural design changes on the experiment definition will be determined. Base research for F.Y. 1992 will emphasize the further development of the Observer/Kalman Filter Identification (OKID) method for system identification. On-line implementation of the method for use in adaptive control studies is the key objective. A new

area related to the dynamics and control of articulated systems is beginning, with the delivery of a seven degrees-of-freedom experimental robotic testbed projected for second quarter delivery. The testbed, which will have flexible links, will be used to define large-motion suspension methods and nonlinear kinematic control.

Interdisciplinary Research Office

During F.Y. 1992 the emphasis of the research will be on applying and validating integrated multidisciplinary optimization methods for three applications (fig. 91.): high-speed aircraft, rotorcraft, and controls-structure integrated optimization of spacecraft. In the high-speed aircraft area, Interdisciplinary Research Office researchers are active participants in optimizing the aircraft configurations and structure in the HiSAIR project at Langley. Near-term work involves integrating aerodynamics, structures, and performance in the design process. In the rotorcraft activity, emphasis will be on developing and testing a fully-integrated aerodynamic-structural optimization procedure for the helicopter rotor blade and a comprehensive validation activity for the rotorcraft optimization methods in which analytically-designed blades will be fabricated and tested to assess optimality and behavior of the designs. In the controls-structure integration research, an optimization procedure developed in the past year for simultaneously optimizing a structure and control system will be extended to incorporate optimal placement of sensors and actuators.

CONCLUDING REMARKS

This publication documents the F.Y. 1991 accomplishments, research and technology highlights and F.Y. 1992 plans for the Structural Dynamics Division.

LANGLEY RESEARCH CENTER

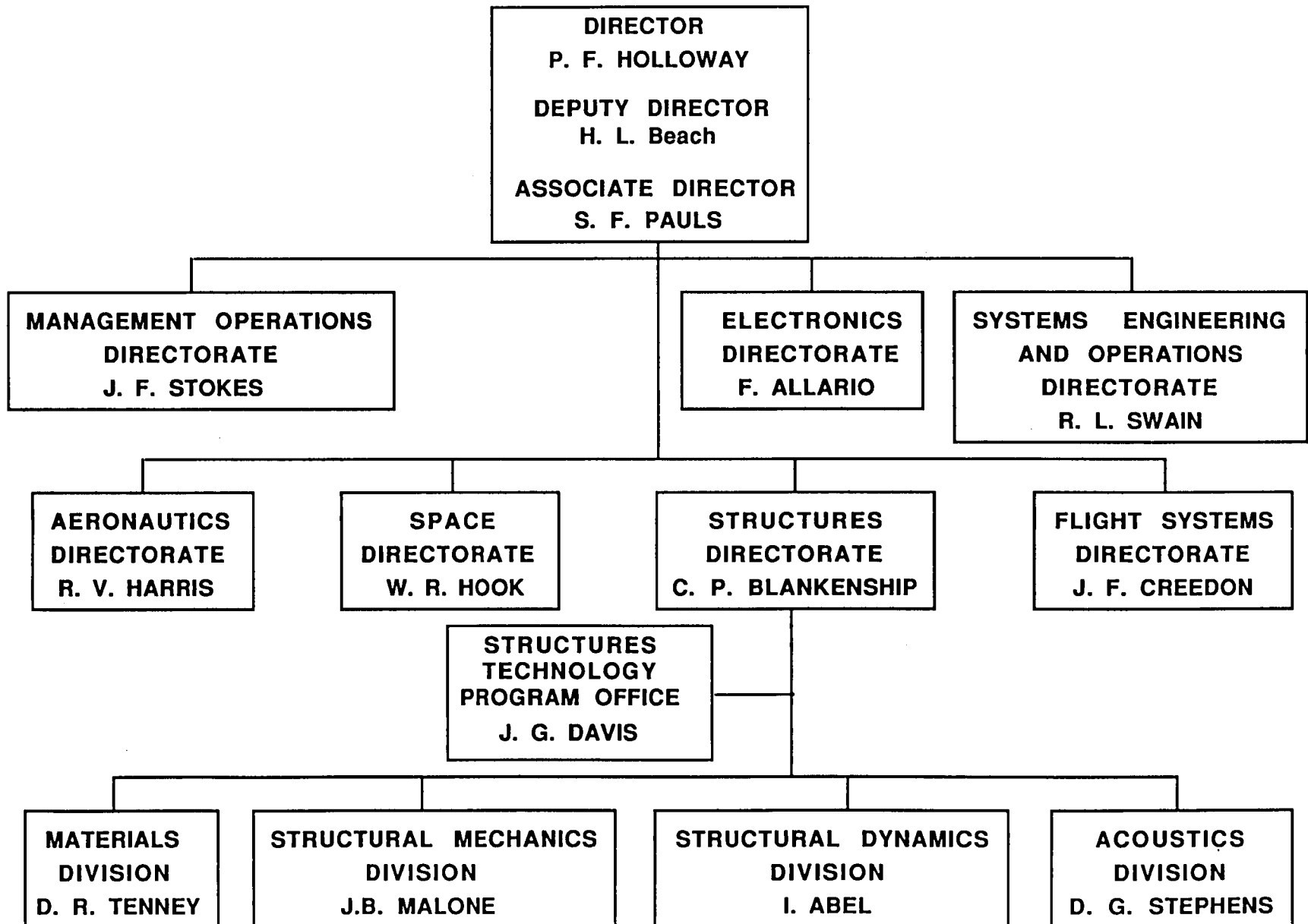


Figure 1.

STRUCTURAL DYNAMICS DIVISION
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**AEROSERVOELASTICITY
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DESIGN METHODS
APPLICATIONS

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AERODYNAMICS
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APPLICATIONS
VALIDATION

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R/C AEROELASTICITY

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CSI GROUND TEST METHODS
**OPTIMAL SPACECRAFT
PERFORMANCE**
MISSION DYNAMICS

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DESIGN METHODS
ALGORITHMS
APPLICATIONS

**LANDING AND IMPACT
DYNAMICS BRANCH**
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TIRE MODELING
CRASH DYNAMICS

Figure 2.

STRUCTURAL DYNAMICS DIVISION

LONG RANGE THRUSTS

AERONAUTICS

- TRANSPORT AIRCRAFT
 - * AEROELASTICITY
 - * LANDING AND IMPACT DYNAMICS
- HIGH PERFORMANCE AIRCRAFT
 - * AEROELASTICITY
- ROTORCRAFT
 - * AEROELASTICITY
- ANALYTICAL METHODS

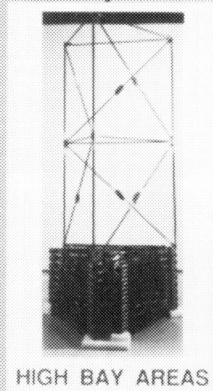
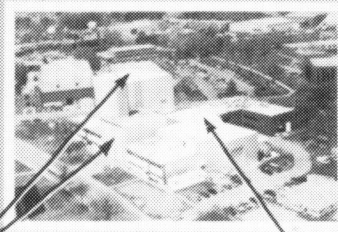
SPACE

- LARGE SPACE STRUCTURES
 - * STRUCTURAL DYNAMICS
 - * CONTROL STRUCTURES INTERACTION

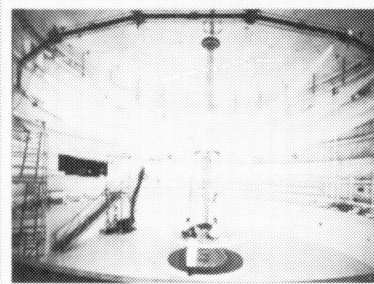
Figure 3.

STRUCTURAL DYNAMICS DIVISION

SPACECRAFT DYNAMICS LABORATORY

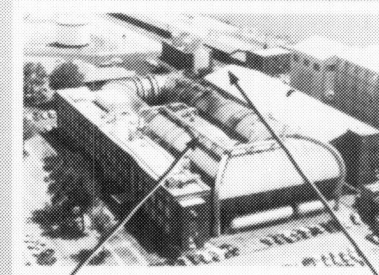


HIGH BAY AREAS



16M THERMAL VACUUM CHAMBER

TRANSONIC DYNAMICS TUNNEL

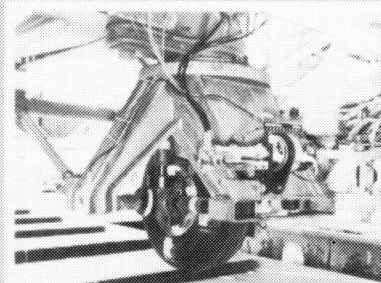


TDT

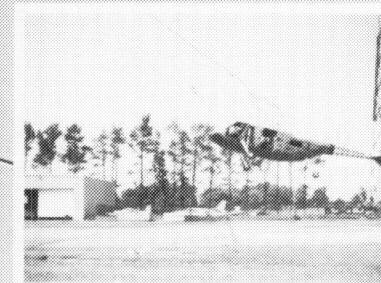


HOVER FACILITY

LANDING AND IMPACT DYNAMICS FACILITY



AIRCRAFT LANDING DYNAMICS



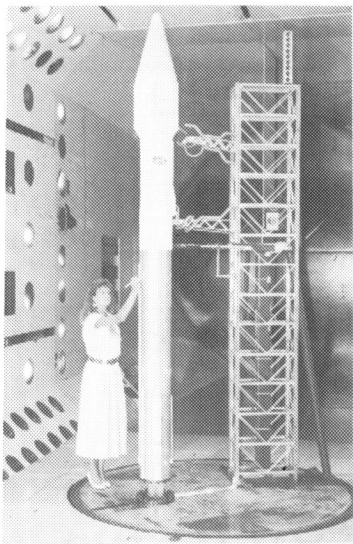
IMPACT DYNAMICS

Figure 4.

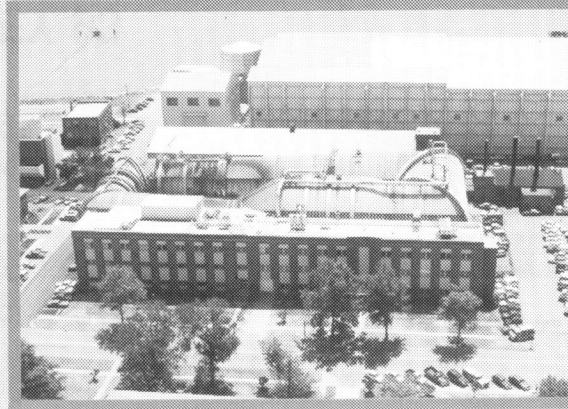
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CONFIGURATION AEROELASTICITY

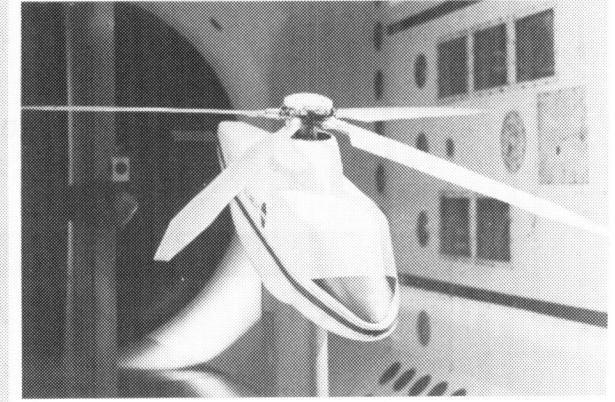
SPACECRAFT



TRANSONIC DYNAMICS TUNNEL



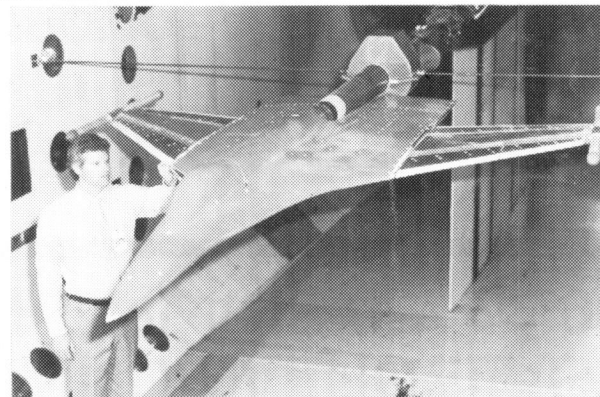
ROTORCRAFT



BENCHMARK MODEL



AIRCRAFT



HIGH-SPEED ROTORCRAFT

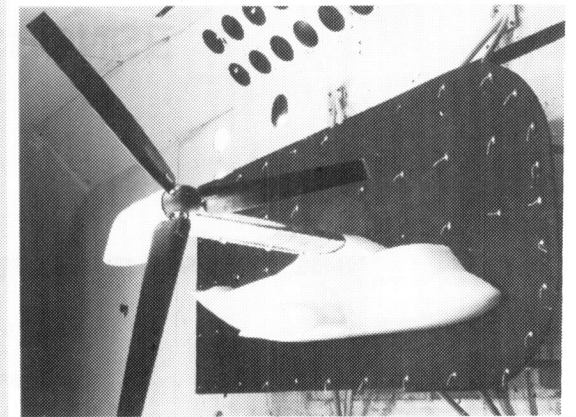


Figure 5.

CONFIGURATION AEROELASTICITY FUTURE PLANS (FY 92-96)

GOAL

PREDICTION AND CONTROL OF AEROELASTIC RESPONSE

KEY OBJECTIVE

- 36 ● UNDERSTAND/IMPROVE AEROELASTIC CHARACTERISTICS OF
ADVANCED FLIGHT VEHICLES

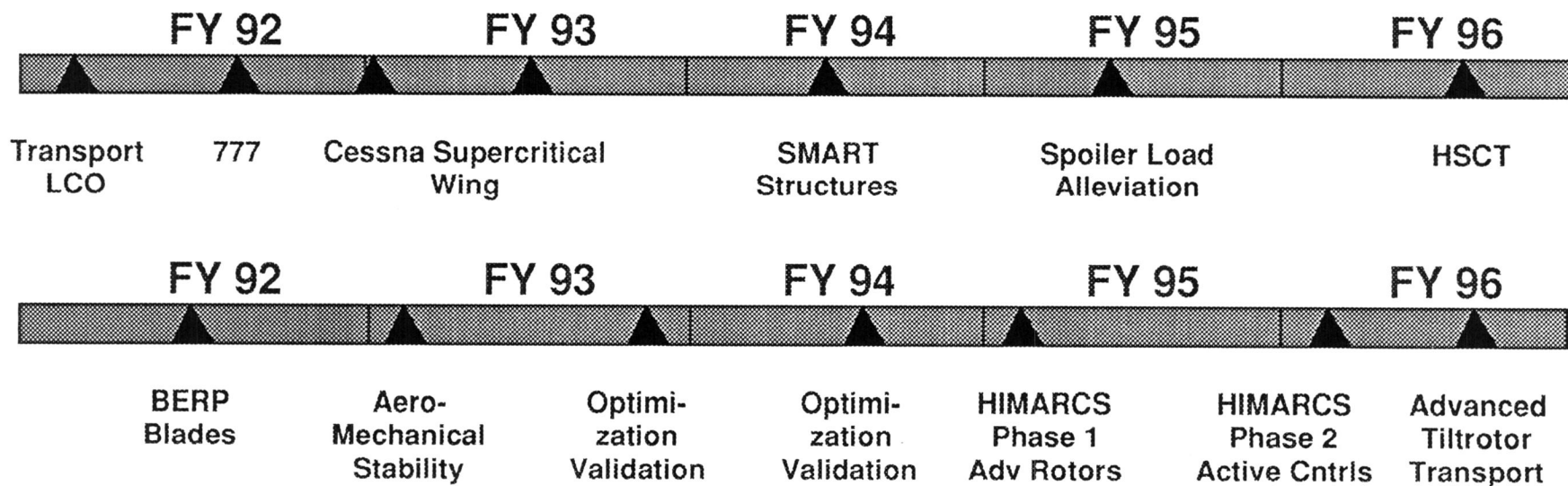
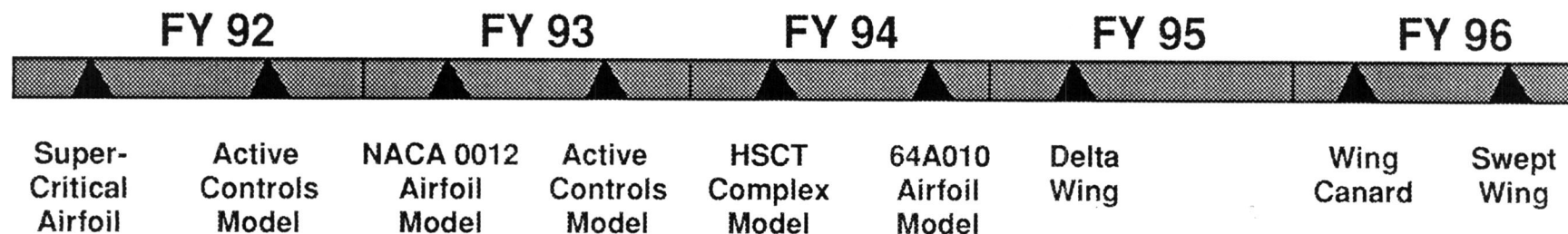


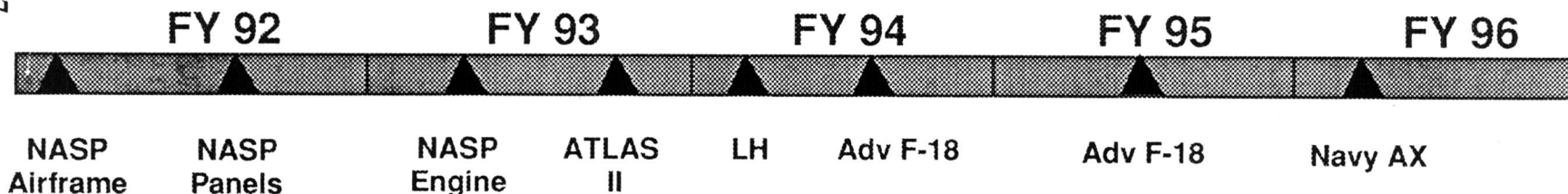
Figure 6 (a).

- ACQUIRE BENCHMARK DATA FOR CFD VALIDATION



- VERIFY THAT NEW NASA/DOD FLIGHT VEHICLES HAVE ADEQUATE AEROELASTIC PROPERTIES

37



- MAINTAIN TDT AS A UNIQUE NATIONAL FACILITY

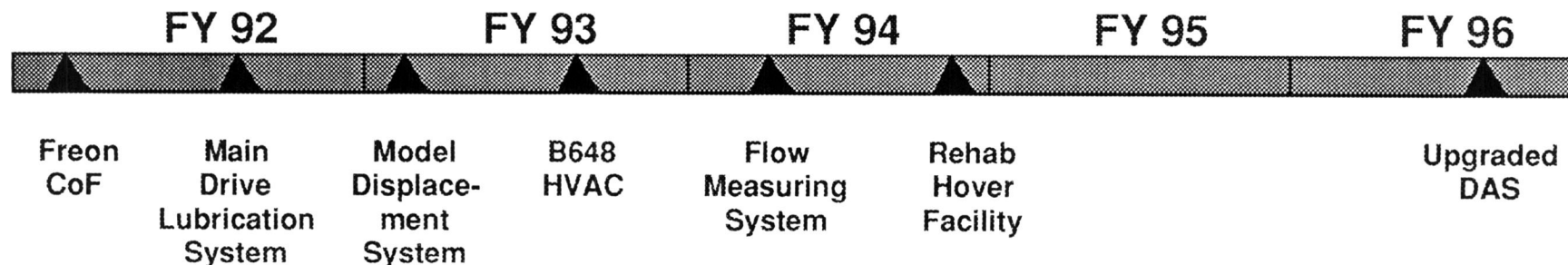


Figure 6 (b).

MULTIPLE FUNCTION ACTIVE CONTROL SYSTEM DEMONSTRATED IN TDT

Stanley R. Cole
Configuration Aeroelasticity Branch

Boyd Perry III
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: A joint NASA LaRC/Rockwell effort, known as the Active Flexible Wing (AFW) Program, was undertaken to design and implement multi-input/multi-output, multifunction digital control of aeroelastically influenced phenomena. The primary program goal was to operate the AFW wind-tunnel model above its flutter boundary using active flutter suppression (FS) while simultaneously demonstrating rolling maneuvers in which the wing loads were actively controlled. The research objectives of the program were to validate the analysis, synthesis, simulation, and test methodologies utilized to perform this demonstration.

Approach: The AFW model is shown mounted in the Langley Transonic Dynamics Tunnel (TDT) in the accompanying figure. The model is a sophisticated, aeroelastically scaled version of an advanced fighter concept which was configured so that flutter would occur within the operating envelope of the TDT. The model was mounted to a sting support in a manner which allowed the model to have freedom to roll during testing. A multiple-exposure photograph of the model at several different roll positions is also shown in the accompanying figure. Two wind-tunnel tests were conducted in the TDT to achieve the program objectives. During the first test, flutter boundaries were determined, several FS systems were tested, and data were gathered for future application to achieve the roll control testing. The second test involved testing of several FS and roll control laws and culminated in the simultaneous testing, above the open-loop flutter boundary, of four different combinations of FS and roll control laws.

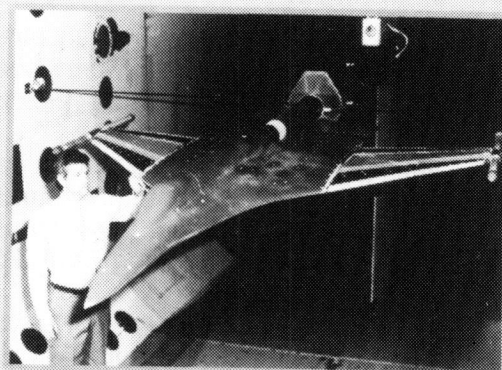
Accomplishment Description: Two wind-tunnel tests of the AFW model have been completed. Simultaneous FS and load control during rolling maneuvers was demonstrated during the second test. The accompanying figure includes a bar chart which summarizes key accomplishments of the AFW program. Four FS control laws, which were tested individually, each allowed the model to be tested at dynamic pressures at least 23 percent beyond the open-loop flutter condition which was at the operating limit of the TDT facility. The figure also shows that a rolling maneuver load alleviation (RMLA) control law was simultaneously tested with FS at conditions 11 percent beyond open-loop flutter and that a roll rate tracking system (RRTS) control law was simultaneously tested beyond flutter by 17 percent. As with FS alone, the dynamic pressure conditions at which FS and roll control laws were tested simultaneously were not limited by stability degradation of the control laws.

Significance: The wind-tunnel tests demonstrated the ability to perform multiple function active control beyond the open-loop flutter boundary during rolling maneuvers. This capability can translate into structurally lighter, more agile fighters which could be configured for certain missions to carry heavier payloads than comparable aircraft which do not use such active control system technology.

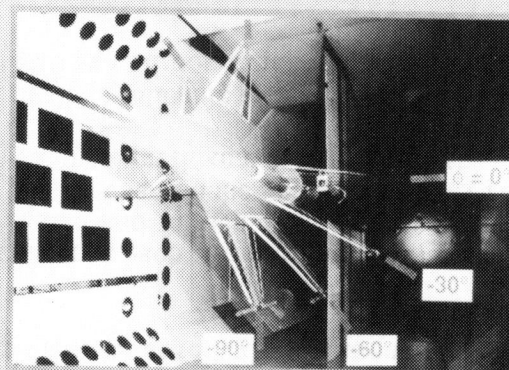
Future Plans: Results from this program will be documented in a number of formal technical reports and will be presented as a compilation in two technical sessions of the 1992 AIAA Dynamics Specialists Conference.

Figure 7 (a).

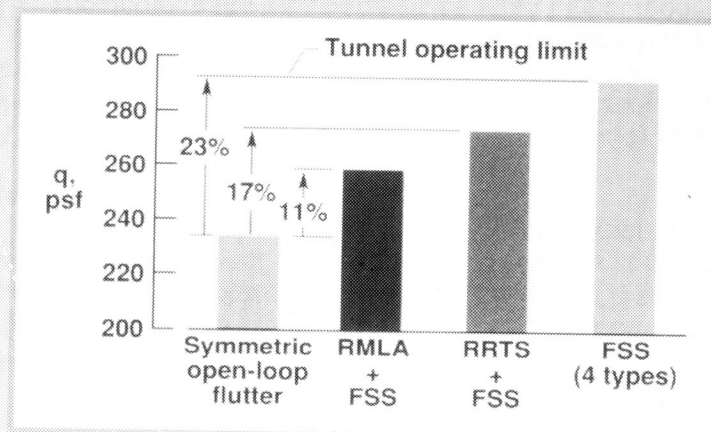
MULTIPLE FUNCTION ACTIVE CONTROL SYSTEM DEMONSTRATED WITH AFW IN TDT



AFW Model in TDT



AFW at Several Roll Angles



Flutter Suppression and Roll Control

Figure 7 (b).

FLUTTER OF ALL-MOVEABLE NASP-LIKE WINGS INVESTIGATED FOR MODEL TESTING IN HYPERSONIC HELIUM TUNNEL

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Lockheed Engineering and Sciences Co., and Configuration Aeroelasticity Branch

RTOP 763-23-41

Research Objective: The all-moveable clipped delta-wing currently envisioned for the National Aerospace Plane (NASP) could potentially encounter aeroelastic problems because of its size, flexibility, hostile environment, and the fact that it must pivot on a single actuator shaft attached along the root chord. The objectives of this research are (1) to investigate flutter characteristics of this wing at hypersonic speeds, (2) to evaluate the applicability of simple predictive methods at hypersonic speeds, and (3) to demonstrate the feasibility of flutter testing in LaRC's Hypersonic Helium Tunnel (HHT), Aerodynamics Leg. This work is in support of the NASP Government Work-package on Vehicle Flutter.

Approach: Miller and Hannah (NASA TM X-325, 1960) and Goetz (TN D-2360, 1964) provided experimental data on flutter of all-moveable delta-wings at Mach numbers of 7 and 15.4 respectively. A finding common to these and other past investigations is that airfoil thickness and leading edge bluntness can dramatically affect hypersonic flutter boundaries. Information from these reports along with present analysis using finite element structural models and piston theory aerodynamic analysis were used in developing wind tunnel model concepts for the HHT. The photo in the figure shows the wind tunnel model with a sharp leading edge and a 4% thick, diamond shaped airfoil with a flap/pitch flexure attached at the 60% root chord position. Four airfoil shapes to be used are shown in the lower left of the figure. Also, several flap/pitch flexures will be used in combination with ballasts to vary the flutter boundaries. The various configurations will be tested throughout the range of HHT conditions depicted in the upper right of the figure. Also shown here are the predicted flutter boundaries for the sharp diamond airfoil configuration with some variations due to flexure thickness and ballast.

Accomplishment Description: Following development of the model concepts, each configuration was analyzed for flutter in the HHT. Based on the results, wind tunnel model components were designed and fabricated. A ground vibration test was then conducted in order to determine vibration frequencies and mode shapes. The bar chart on the lower right gives a comparison between analytical and experimental frequencies for the sharp diamond model with the medium flexure and light ballast.

Significance: These tests will be the first hypersonic flutter tests specifically applicable to the NASP and will provide data to be used in vehicle design and analytical code development. This investigation will compliment similar wing and vehicle flutter experiments at transonic and supersonic speeds.

Future Plans: Wind tunnel testing of these models in the HHT is scheduled for early 1992.

Figure 8 (a).

FLUTTER OF ALL-MOVEABLE NASP-LIKE WINGS INVESTIGATED FOR MODEL TESTING IN HYPERSONONIC HELIUM TUNNEL

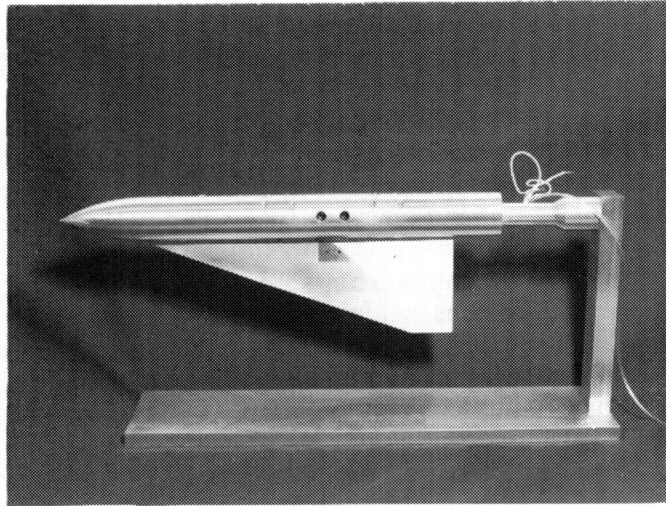
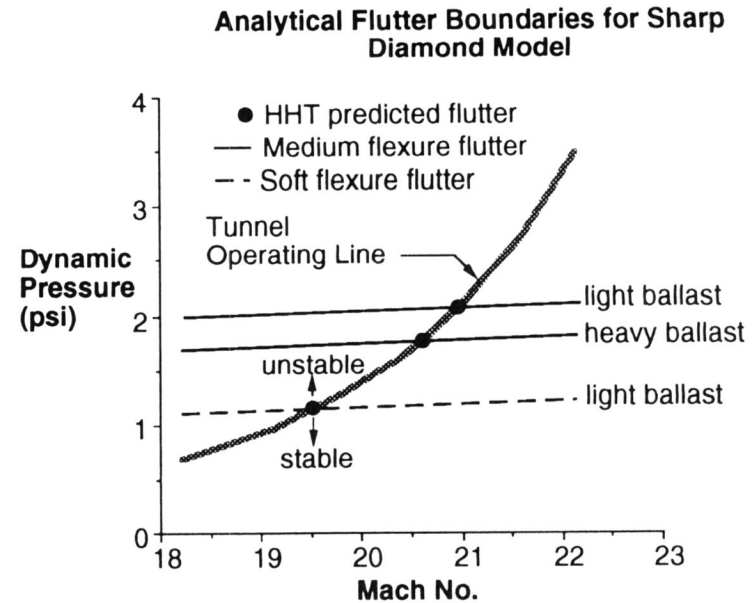
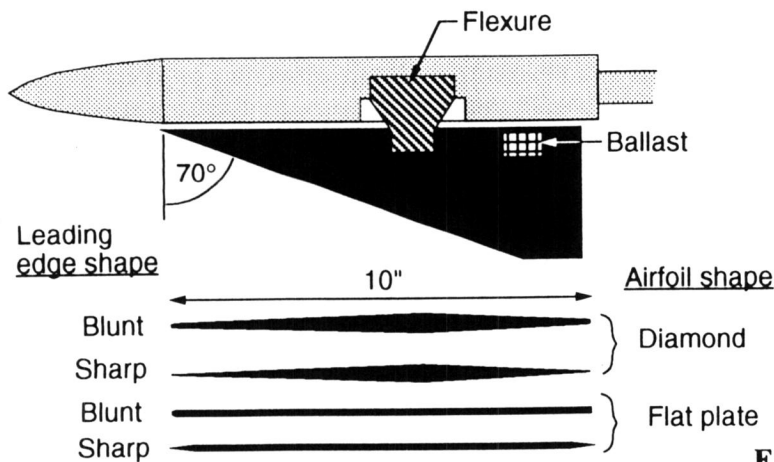


Photo of HHT Model



Model Configuration



Vibration Test Results for Sharp Diamond Model with Medium Flexure and Light Ballast

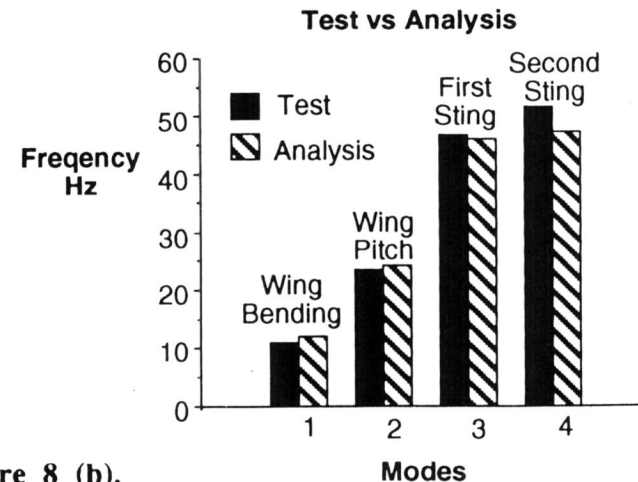


Figure 8 (b).

COMPREHENSIVE BENCHMARK-MODEL-PROGRAM NACA 0012 MODEL TEST CONDUCTED IN TDT

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Configuration Aeroelasticity Branch, SDyD

Robert M. Bennett and Walter A. Silva
Unsteady Aerodynamics Branch, SDyD

RTOP 505-63-50

Research Objective: A Benchmark Models Program has been initiated at Langley with a primary objective of obtaining data for aeroelastic computational fluid dynamic (CFD) code development, evaluation, and validation. The first model in the series, a wing with a conventional airfoil supported on a flexible mount system, was tested to define the conventional flutter boundary, the angle-of-attack flutter boundary, and other transonic instability boundaries with simultaneous measurements of surface pressures during flutter.

Approach: A rigid rectangular wing of panel aspect ratio 2.0 with a NACA 0012 airfoil was tested in the Transonic Dynamics Tunnel (TDT) on the flexible Pitch and Plunge Apparatus as shown in the accompanying figure. The model was equipped with eighty in situ pressure transducers to measure wing upper and lower surface steady and unsteady pressures. The model and support system were also instrumented with accelerometers and strain gage bridges for measurement of model frequencies, displacements, and forces. A ground vibration test was performed to define the wind-off structural dynamic characteristics of the model system. Wind-on data were obtained in the Mach number range from 0.3 through 0.97.

42

Accomplishment Description: Two wind-tunnel tests have been completed. Information gathered during the first test was used to define the scope and guide the second, more comprehensive, test. This second test gathered data for CFD code development, evaluation and validation. Mach number effects on the conventional flutter boundary (coupling of pitch and plunge modes) for the model at zero-degrees alpha (angle-of-attack) are shown as a function of dynamic pressure and Mach number in the data plot at the upper left of the figure. A narrow instability region is also shown near Mach number 0.90 in which the mode of oscillations was primarily plunge motion. Angle-of-attack effects on model flutter at Mach number 0.78 are shown in the plot at the lower left portion of the figure. At angles-of-attack greater than about 4-deg the motion was primarily in the pitch mode and is considered to be shock induced stall flutter. At other Mach numbers (not shown) the transition to stall flutter occurred at somewhat different angles of attack. Wing upper and lower surface steady (with the mount system rigidized) and unsteady (flexible mount system) pressures were measured along chordlines at the 60 and 95 percent span stations. Samples of upper-surface unsteady pressure distributions measured during flutter are shown in the lower portion of the figure. The mean pressure coefficients, C_p , are plotted as a function of chord location for $M=0.51$ on the left, and $M=0.77$ on the right. Instrumentation time history records were recorded at most instability points with samples shown in the figure. From these, the flutter frequency, and unsteady pressure magnitude and phase relative to the flutter motion can be determined for correlation with analytical results to assist with CFD code evaluation. Flow studies were also performed using both tufts and liquid crystals to define shock locations and lines of separation. The upper right portion of the figure shows an example of liquid crystals indicating the location of the shock as the light colored line on the model surface.

Significance: The availability of a comprehensive data set defining model structural dynamic characteristics and measured model instability boundaries (flutter, etc.) along with associated steady and unsteady pressure measurements and surface flow visualization is expected to be a useful tool for the development, evaluation, and validation of CFD methods.

Future Plans: Data reduction is ongoing. Final results will be documented in a series of formal publications. A third test is planned in which the model will be tested in a heavy gas to gather data at higher Reynolds numbers.

Figure 9 (a).

COMPREHENSIVE BENCHMARK-MODELS-PROGRAM NACA0012 MODEL TEST CONDUCTED IN TDT

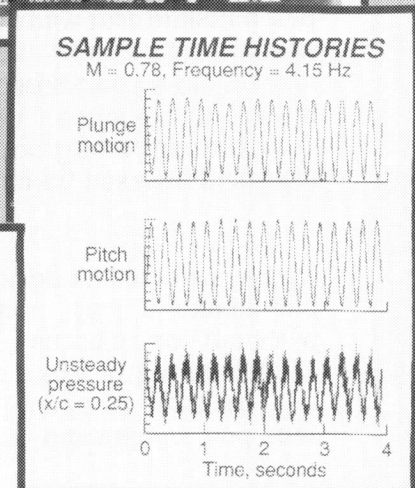
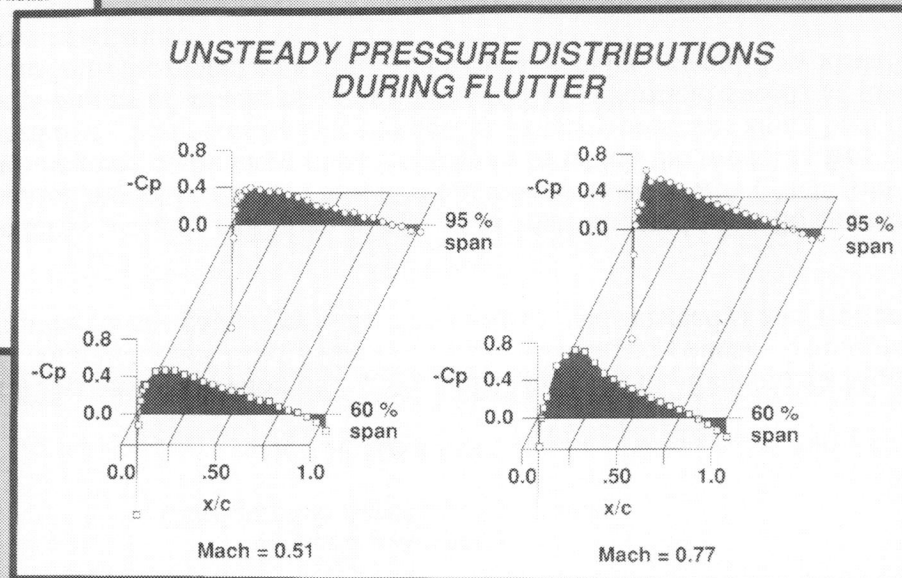
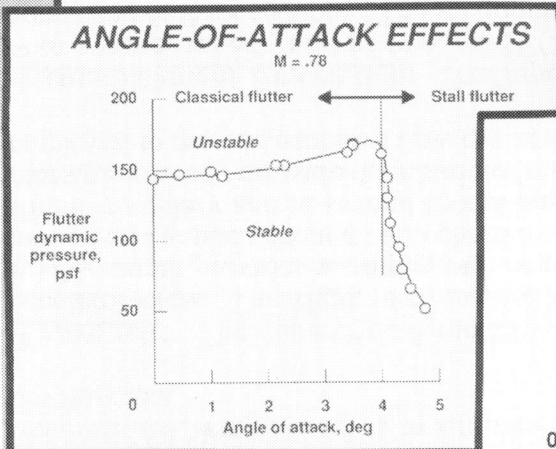
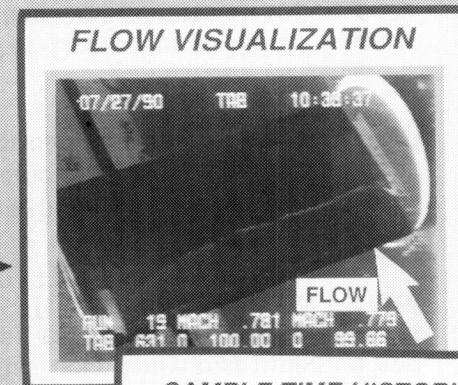
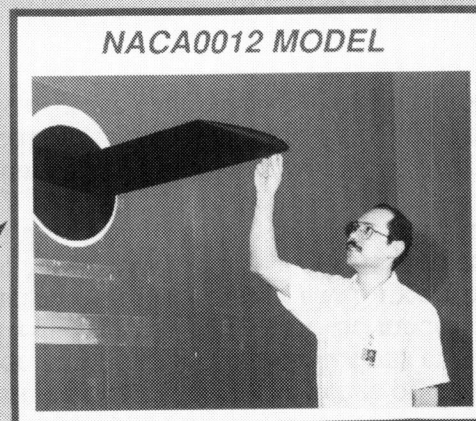
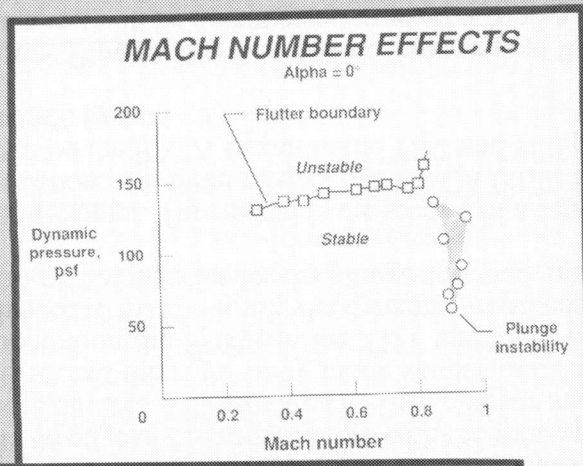


Figure 9 (b).

BENCHMARK SUPERCRITICAL WING READY FOR TESTING IN TDT

Bryan E. Dansberry
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The Structural Dynamics Division of NASA, LaRC initiated the Benchmark Models Program, to facilitate the development and evaluation of computational fluid dynamic (CFD) aeroelastic codes. The objective of the Benchmark Supercritical Wing Model is to simultaneously gather pressure (both steady and unsteady) and flutter data for analytical code development.

Approach: The supercritical model is a rigid, half-span wing. It is instrumented with 80 pressure transducers and four accelerometers. This rigid, instrumented model is attached to a flexible mount called PAPA (Pitch And Plunge Apparatus). The PAPA mount provides a simple, two-degrees-of-freedom dynamic system in which the model is free to move in a rigid plunge motion and to pitch about its mid-chord line. Test plans include measuring unsteady pressures along both the subsonic and transonic flutter boundary and at several model angles of attack, obtaining pressures at subcritical speeds at several Mach numbers, and measuring steady pressure distributions with the model on a rigidized mount. Finally, several flow visualization techniques will be employed to record qualitative flow characteristics.

44 **Accomplishment Description:** The Supercritical Model, constructed from solid aluminum, has a rectangular, unswept planform with a panel aspect ratio of two, an SC(2)0414 airfoil section, and a tip-of-revolution. As shown in the figure, the model is composed of three sections. The section breaks allow access to the in-situ pressure transducers, 40 of which are mounted along the outside edge of the root section, with the remainder mounted along the outside edge of the mid-section and protected by the tip cap. These devices will provide chordwise upper and lower surface pressure distributions at 60% and 95% span. Four accelerometers will record the rigid-body mode shapes and flutter frequency. A picture of the model, which has been fully instrumented and mounted on the PAPA in the TDT test section, is included in the figure. The Supercritical Wing model/PAPA system is mass balanced to match closely the dynamic properties of the NACA 0012 PAPA model tested previously. The experimentally determined wind-off frequencies for the plunge and pitch modes of the model/PAPA system are 3.33 Hz and 5.24 Hz respectively.

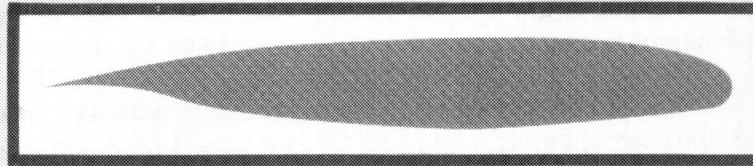
Significance: This model is the second of a series of three similar models designed to provide a data-base for CFD aeroelastic code evaluation. All three models (the NACA 0012, Supercritical, and 64A010) are rigid, and have the same planform. They are all to be tested on the PAPA mount in the TDT and will provide experimental pressure data on a model experiencing flutter in a well defined dynamic system.

Future Plans: The Benchmark Supercritical Wing is scheduled for testing in the TDT in November-December of 1991. Results of the test will be documented in several NASA Technical Memoranda to disseminate the data. A technical report will follow once all the results have been analyzed. A "work-in-progress" paper has been proposed for the SDM conference in April, 1992.

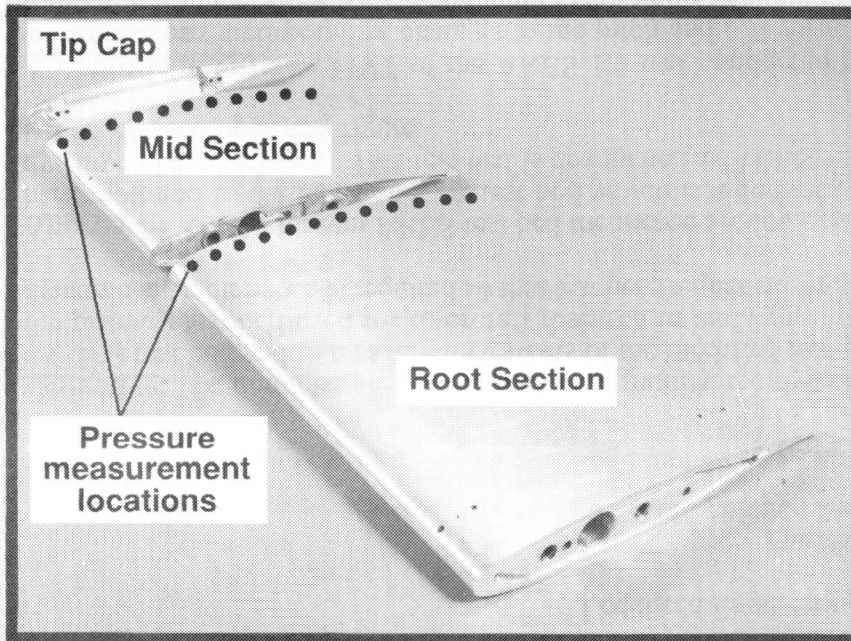
Figure 10 (a).

BENCHMARK SUPERCRITICAL WING READY FOR TESTING IN TDT

SC(2) 0414 Airfoil Shape



Model Assembly



Model Mounted in TDT



Figure 10 (b).

CAPABILITIES OF MODIFIED ARES TEST BED DEMONSTRATED IN TDT

M-Nabil H. Hamouda
Lockheed Engineering & Sciences Company

Paul H. Mirick
Configuration Aeroelasticity Branch

RTOP 505-63-36

Objective: To demonstrate the capability to modify the dynamic characteristics of the Aeroelastic Rotor Experimental System (ARES) test bed and to measure the effects of the modified dynamic characteristics on fixed-system vibratory loads. The ARES is the primary test bed used for rotorcraft research in the Transonic Dynamics Tunnel (TDT). A method of modifying the test bed dynamic characteristics is required so that test bed frequencies might be adjusted to avoid undesired rotor/body instabilities.

Approach: On the current ARES test bed the metric section components (motor, drive train, rotor, control system, and balance) are hard mounted to the test stand. A test bed which is a derivative of the current ARES has been developed to modify the system dynamic characteristics. This test bed is designated as ARES 1.5. The mounting features of the ARES 1.5 are shown in the upper left of the accompanying figure.

Accomplishments: A GVT of the ARES 1.5 was conducted to determine the dynamic characteristics of the test bed. Several configurations incorporating changes to the pitch and roll springs and dampers as well as the method of mounting the model test stand to the tunnel floor were examined. GVT test results for the ARES 1.5 with and without the pitch and roll dampers produced changes from the original ARES pitch and roll frequencies, as shown in the lower left of the figure. The GVT was followed by a tunnel test of ARES 1.5 to check the system and to evaluate the effect of different configurations on fixed system loads. A four bladed articulated rotor was used for this test. During the test four configurations of the ARES 1.5, as well as the original ARES configuration, were tested in hover and forward flight up to an advance ratio of 0.35. The fourth harmonic component of the measured fixed system normal force from the wind tunnel test are presented in the lower right of the figure to show the changes between test bed configurations. Similar results were obtained for the other fixed system loads.

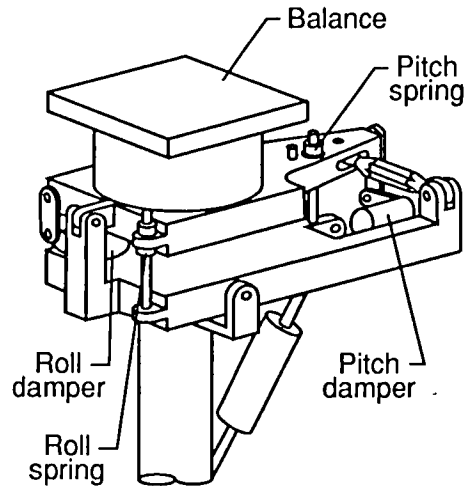
Significance: This test demonstrated the capability to tune the ARES test bed dynamic characteristics. Use of this capability will allow for safer testing of advanced rotors as well as accommodate testing of a wider range of model rotors. However, the higher fixed-system loads associated with the ARES 1.5 should be taken into consideration in future loads tests.

Future Plans: Additional GVT's of ARES 1.5 will be conducted with different settings of viscous damping to determine the effect on the test bed dynamic characteristics. Hover and forward flight tests will also be conducted with the hingeless rotor mounted on the ARES 1.5 to evaluate the effect of the ARES 1.5 tuning capability on aeromechanical stability.

Figure 11 (a).

CAPABILITIES OF MODIFIED ARES TEST BED DEMONSTRATED IN TDT

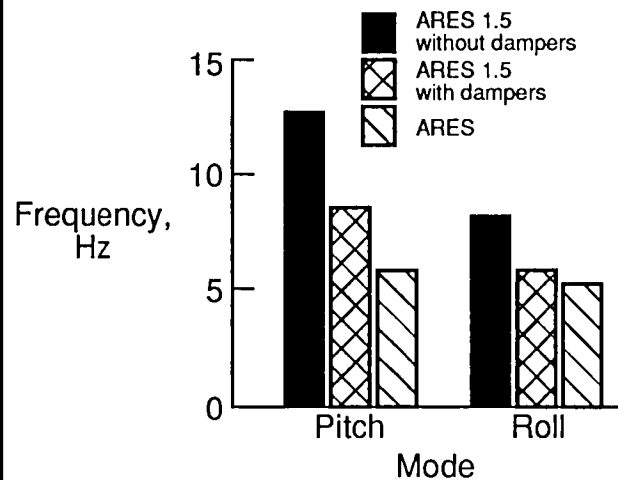
ARES 1.5 FEATURES



ARES 1.5

- Alternate method of mounting metric section
- Metric section mounted on dampers and springs
- Model frequencies and damping adjustable

MODEL FREQUENCIES



4th HARMONIC COMPONENT OF NORMAL FORCE

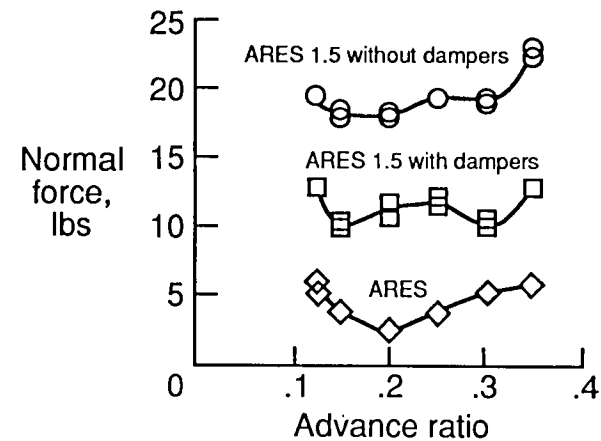


Figure 11 (b).

PARAMETRIC BEARINGLESS HUB (PBH) BEING DEVELOPED FOR TDT TESTING

Paul H. Mirick and William K. Wilkie
Configuration Aeroelasticity Branch

RTOP 505-63-36

Objective: To develop a bearingless rotor hub for use on the Aeroelastic Rotor Experimental System (ARES) test-bed. It will be used for tests to generate a data base which quantifies the effects of critical bearingless rotor design parameters on aeromechanical stability, fixed system vibrations, and rotor loads.

Approach: A rotor hub which allows several design parameters such as precone, pretwist, prelag, predroop, flap frequency, and lag frequency to be easily changed has been designed and fabricated. Tests will now be performed on critical components of the hub to verify their structural integrity, to gain confidence in the analyses used in the design process, and to identify areas where the hub design can be improved. Based on the results of these tests the design will be refined and subjected to additional tests to substantiate the design changes prior to hover and wind tunnel tests.

Accomplishments: Several concepts for bearingless rotor hubs were examined and a concept selected for the PBH. An initial design of the hub has been completed and all parts have been fabricated. Two different flexure designs which have a constant thickness rectangular cross section have also been fabricated. Tests of the flexures were conducted to determine their flap, lag, and torsional stiffness, and natural frequencies. The results of these tests were then compared with the results predicted by a NASTRAN model of the flexure. Excellent agreement between the analytical predictions and tests results was obtained.

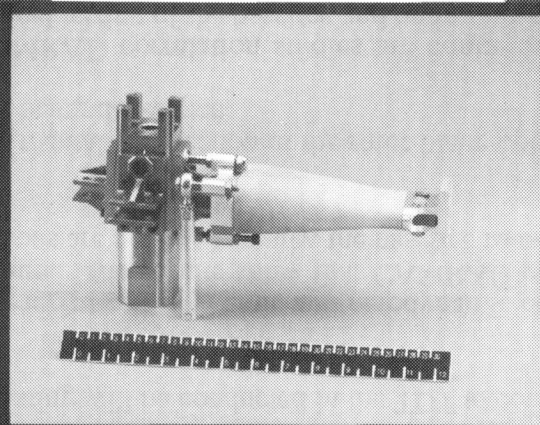
Significance: The development of the PBH will allow testing to establish an extensive data base quantifying the effects of changes in several key parameters on rotor stability, fixed system vibrations, and rotor loads. This data base of design change effects will be available for use by designers for the development of new bearingless hubs and by developers of computer codes to verify their analyses capabilities.

Future Plans: The critical element of this program is the design of the flexure. Target flap and lag frequencies for the rotor hub have been established; however, modeling of the system is quite complex. Preliminary results using NASTRAN to model the flexure alone under static conditions have been very encouraging. The modeling of the complete hub and blade with static loads and with loads associated with rotation is currently being conducted. A shake test of the hub will be conducted to verify the math model under static loading conditions. Once these tasks are completed, a new flexure will be designed to more closely achieve the desired target frequencies. This new flexure will then be fabricated and tested to verify its structural integrity and dynamic characteristics. Hover testing of the rotor hub will then be conducted to investigate aeromechanical stability of the hub. Upon successful completion of these tests a wind tunnel test of the PBH will be conducted in the TDT.

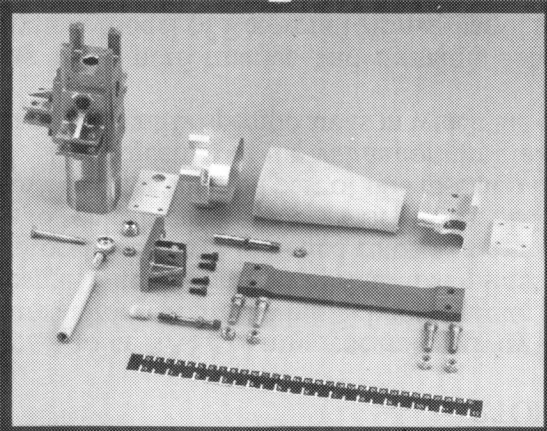
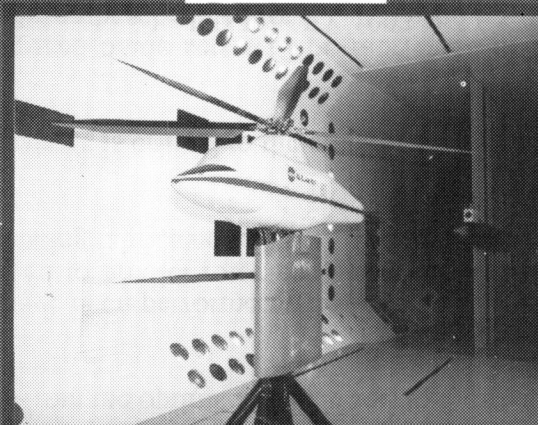
Figure 12 (a).

PARAMETRIC BEARINGLESS HUB (PBH) BEING DEVELOPED FOR TDT TESTING

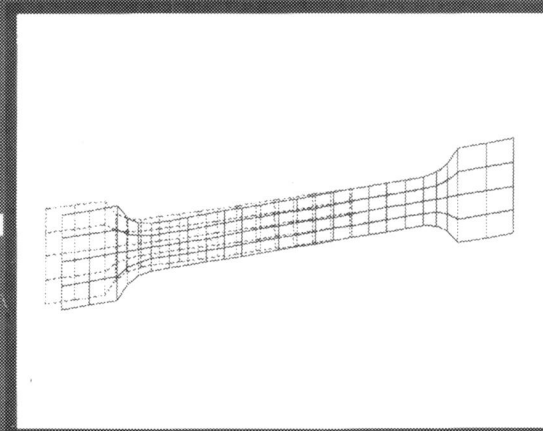
**Single Cuff/Flexure Assembly
for PBH**



ARES Model



PBH Components



NASTRAN Analysis of Flexure

Figure 12 (b).

ROTORCRAFT OPTIMIZATION VALIDATION AT THE TRANSONIC DYNAMICS TUNNEL IN PROGRESS

Matthew L. Wilbur and William T. Yeager, Jr.
Configuration Aeroelasticity Branch

RTOP 505-63-36

Research Objective: A joint NASA/Army research activity has been initiated at the NASA Langley Research Center to develop optimization procedures aimed at improving helicopter rotor blade design processes. This research involves a multidisciplinary approach to rotor design, integrating appropriate disciplines and accounting for important interactions among the disciplines. Initially, the design procedures have included rotor aerodynamic performance optimization for minimum horsepower and rotor dynamic optimization to achieve minimum vibratory loads. Additionally, constraints have been applied to limit the rotor blade weight and rotor acoustic signature. An integral part of this research has been the development of a program to experimentally validate the optimization process. The objective of the validation program is to experimentally determine the effectiveness of the developed optimization process and to identify specific areas in which the optimization procedures must be improved.

Approach: Existing rotor performance and dynamic loads wind-tunnel data are being correlated with results from the Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics (CAMRAD) computer code. Since CAMRAD is the primary program being used in the optimization procedures, the results of this correlation study will help to build confidence in the disciplines in which CAMRAD is strong and identify areas in which more "engineer-in-the-loop" judgement must be used. Additionally, aeroelastically scaled model rotor blade hardware will be fabricated for testing on the Aeroelastic Rotor Experimental System (ARES) in the Transonic Dynamics Tunnel (TDT). This hardware will consist of a baseline rotor blade set and four sets of optimized blades. Testing will be conducted in the TDT to compare results from the optimized blade sets to those obtained with the baseline blade set.

Accomplishment Description: Dynamic and aerodynamic correlations have been performed with CAMRAD, samples of which are shown in the figure. The results show that CAMRAD can be expected to predict rotor performance trends well, however, dynamic load predictions are poor. Currently, the baseline rotor blade set is being fabricated and is to be delivered in the first-quarter of FY 1992.

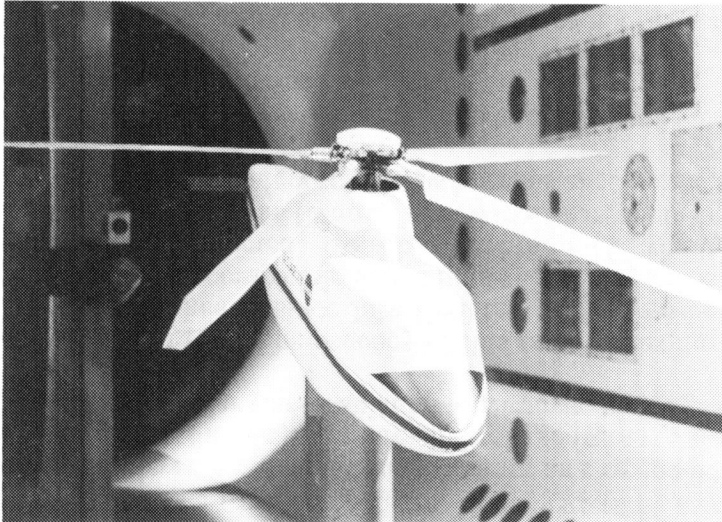
Significance: Experimental verification of the rotor-blade optimization methods is critical to the assessment and acceptance of the procedures which are being developed.

Future Plans: CAMRAD correlation studies are continuing and optimized blade sets will be fabricated as the designs are completed. Wind-tunnel testing of the baseline and optimized blade sets is currently scheduled for FY 1993 and FY 1994.

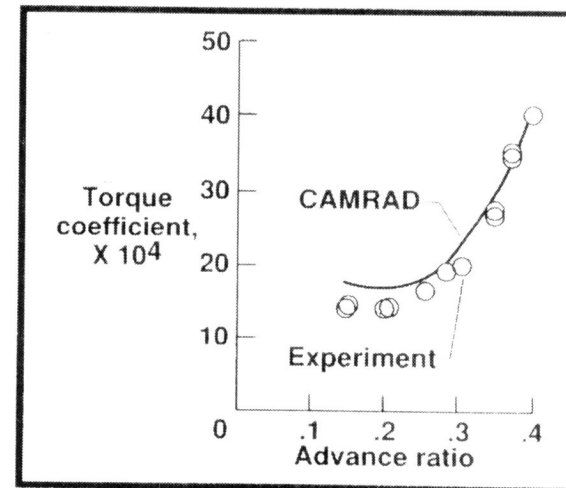
Figure 13 (a).

ROTORCRAFT OPTIMIZATION VALIDATION AT THE TRANSONIC DYNAMICS TUNNEL IN PROGRESS

ARES in the Transonic Dynamics Tunnel



CAMRAD Correlation Results



- Analysis correlation for rotor performance and dynamic loads
- Wind-tunnel testing of baseline blade set and for optimized blade sets
- TDT tests scheduled for FY 93 and FY 94

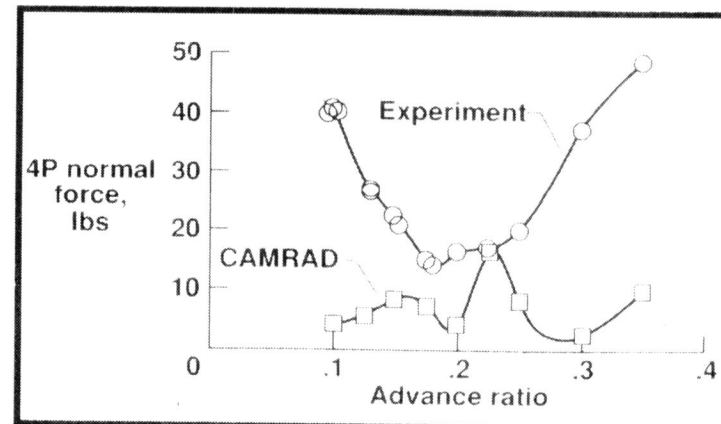


Figure 13 (b).

MODIFICATIONS COMPLETED FOR THE TRANSONIC DYNAMICS TUNNEL HEAVY GAS RECLAMATION SYSTEM

Bryce M. Kepley
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this project is to improve the heavy gas recovery system at the Transonic Dynamics Tunnel (TDT) so that heavy gas losses are essentially eliminated. Reaching this goal will allow the TDT to resume normal operations as a highly functional test facility using heavy gas as the test medium.

Approach: Historically, the TDT has used heavy gas, namely dichlorodifluoromethane (R-12), as the test medium for approximately 95% of test operations since the early 1960's. Heavy gas is approximately four times heavier than air and has a speed of sound about half that of air. This is a significant advantage for testing aeroelastic models at transonic speeds because it allows use of heavier models, requires less tunnel fan horsepower, and provides higher Reynolds number test conditions. Heavy gas is stored as a liquid, vaporized into a gas for test purposes, and reclaimed into a liquid for storage and reuse. The modified heavy gas reclamation system includes a Low Temperature Condenser (LTC) system that is supplied with liquid nitrogen (LN₂) from a new dewar, a two-tower gas dryer, a regeneration system for an existing air dryer, controls and instrumentation. New valves have been installed with scavenging technique to capture any leakage from the stems and flanges. Structural pockets in the plenum have either been ported or filled with cellular glass insulation to eliminate heavy gas entrapment during the removal process.

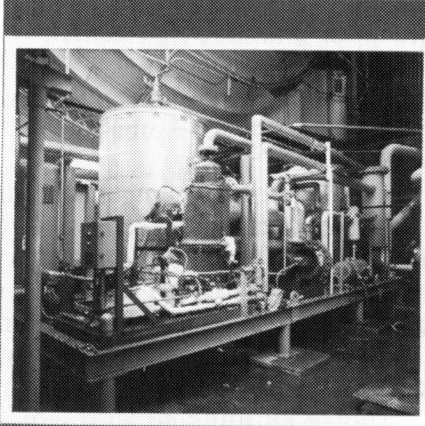
Accomplishment Description: The urgency of this project was the result of the Agency's concern and sensitivity to the loss of R-12 into the environment; hence, since July 1989 this project has been designed, funded, and is nearing completion. The design required that all equipment be compatible with a future alternate gas. All equipment related to reclaiming R-12 has been installed and some degree of checkout completed. Cold box 2 of the LTC which is necessary only for reclaiming sulfur hexafluoride is to be delivered and installed in the near future. A new coil has been installed in the main drive Dynamatic brake and as a safety enhancement a new replacement safety screen has been installed on the turning vane immediately upstream of the main drive fan.

Significance: The TDT should resume a full schedule, two-shift heavy gas operation in November 1991. Heavy gas losses are expected to be less than 1 ton per year.

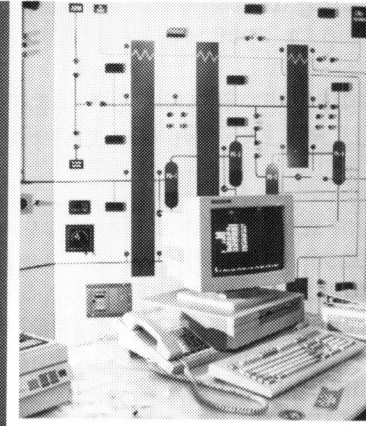
Future Plans: Sulfur hexafluoride (SF₆) has been identified as a replacement heavy gas for the TDT. It is environmentally acceptable and plans are to convert to SF₆ in Fiscal Year 1995.

Figure 14 (a).

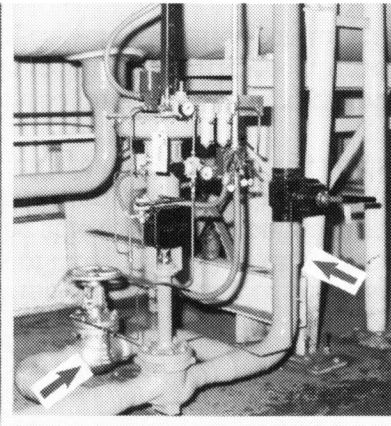
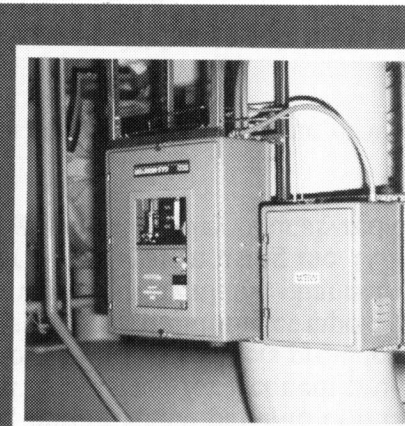
MODIFICATIONS COMPLETED FOR THE TRANSONIC DYNAMICS TUNNEL HEAVY GAS RECLAMATION SYSTEM



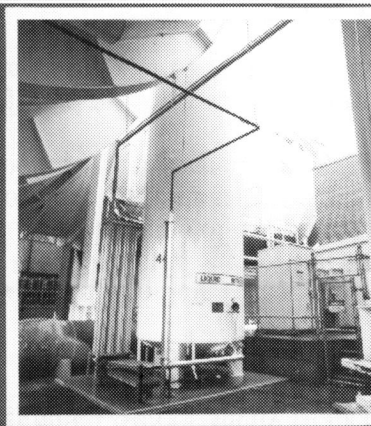
**Low Temperature
Condenser System**



Controls & Instrumentation

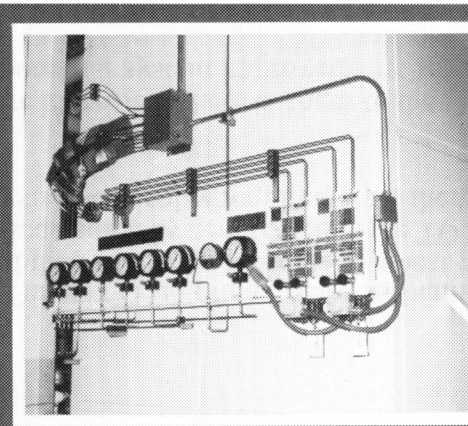


**Typical Valve
Replacement with
Scavenger Tubing**



LN2 Dewar

Figure 14 (b).



**Low Temperature
Condenser System**

HARDWARE IMPROVEMENTS IMPLEMENTED FOR THE TRANSONIC DYNAMICS TUNNEL DATA ACQUISITION SYSTEM

David C. Rosser, Jr.
Configuration Aeroelasticity Branch

RTOP 505-63-50

Objective: Wind-tunnel testing of aeroelastic models in the Langley Transonic Dynamics Tunnel (TDT) often involves obtaining large volumes of data from many different sensors on the model and supporting structure and then analyzing this data in a near real time mode to be able to support continuation of testing. The objective of improving the Data Acquisition System (DAS) at the TDT is to provide the test engineers with the tools needed to meet these near real time data analysis and display requirements, thereby increasing the efficiency, productivity, and safety for the tests performed.

Approach: Based on operational experiences and projected research needs, several areas were identified where changes to the DAS could be made to improve efficiency, productivity, and safety. From the resulting list of potential system improvements several hardware changes were identified for implementation.

Accomplishment Description: Improvements to the DAS hardware were successfully accomplished in several areas. These improvements are illustrated in the accompanying figure. Data storage capability was increased by the installation of two additional hard disk drives for a total of ten. These additional hard drives provides the test engineer the use of a dedicated hard disc drive for the storage of real time data during testing. Buffer amplifiers were added to the NEFF analog output signal paths to eliminate variations of relative drift (time varying offsets) between analog and digital signals. This reduces the need for frequent pre-test manual adjustment of the analog signal levels. The addition of an IPS-2 communications chassis to the DAS computers provides the capability to transfer information, in near real time, to and from other computers and/or peripherals such eight millimeter tape drives and SCSI hard drives. The addition of a fourth Neff analog to digital interface increased the number of available channels for recording data from 192 to 256. The addition of a color graphics workstation and laser printer to the system using the TCP/IP communications will provide the control room test engineers with the capability for near real time graphical display of analyzed data signals with immediate hardcopy output.

Significance: These hardware additions have increased the operating efficiency of the TDT data acquisition system and provided the test engineers with significant improved data acquisition, display, and analysis capabilities.

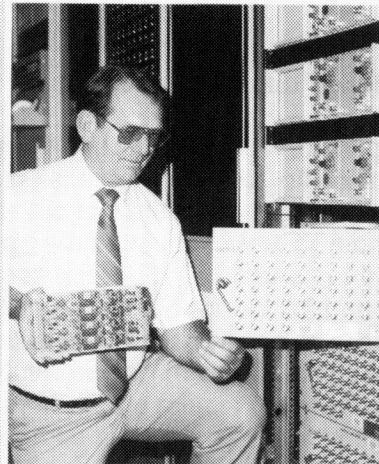
Future Plans: Efforts will continue to identify improvements that could be made to the TDT data acquisition system to increase efficiency, reliability, and accuracy and thus ensuring that the data acquisition system for the TDT continues to be at the forefront of available technology.

Figure 15 (a).

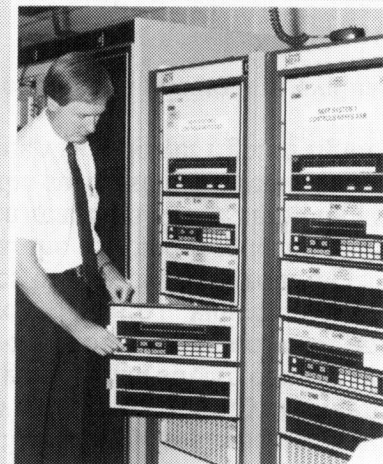
HARDWARE IMPROVEMENTS IMPLEMENTED FOR THE TRANSONIC DYNAMICS TUNNEL DATA ACQUISITION SYSTEM



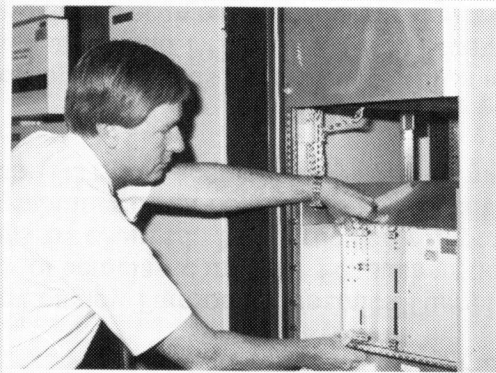
Two Additional Hard Disk



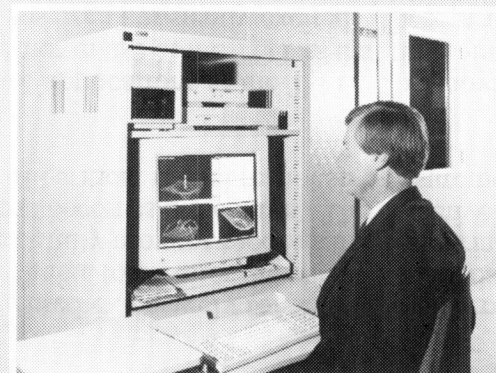
**In-House Designed
Buffer Amplifier Card**



**New Sixty Four Channel
Add-On Analog Front End**



**Transmission Control Protocol
Internet Protocol (TCP/IP)**



**SUN SPARC-2 Series
Colorgraphics Workstation**

Figure 15 (b).

A SUBCRITICAL RESPONSE TECHNIQUE IMPLEMENTED ON THE MODCOMP DATA ACQUISITION SYSTEM AT TDT

David C. Rosser, Jr., Jeffrey D. Singleton, and Matthew L. Wilbur
Configuration Aeroelasticity Branch

William Lee
Wyle Laboratories

RTOP 505-63-21

Research Objective: The Langley Transonic Dynamics Tunnel (TDT) is used extensively for testing to determine stability, loads, and response characteristics of aeroelastic models. For such testing it is desirable to monitor the changes in modal damping as model and/or tunnel test conditions are changed. It is particularly important to carefully monitor model damping during approaches to test conditions where model instabilities occur or where model dynamic response becomes quite large. The objective of this research was to implement, on the current TDT data acquisition system, an interactive subcritical model response measurement technique called moving-block.

Approach: Subcritical response methods have been useful in a variety of applications at the TDT. The moving-block technique was previously implemented in the mid 1970's on a Xerox Sigma V computer in use at the TDT at that time. For the moving-block technique structural response data is acquired immediately after the model has been transiently excited. These structural response data are then analyzed interactively to determine modal frequencies and damping. The current approach is to implement this previously-used technique on the present TDT MODCOMP data acquisition system.

Accomplishment Description: The moving-block technique has been programmed as an applications program on the MODCOMP computer system and integrated into the Data Acquisition and Monitor Program (DAMP). DAMP is an interactive program used for control of the data acquisition system functions. The first application of the newly implemented method was to determine the stability of a hingeless helicopter rotor model. Some typical results are shown in the accompanying figure. The first step in the process is to obtain the structural response signal (upper left of figure) from a digitized data stream coming directly from the model which was excited with a sinusoidal control input and then allowed to decay freely. Once the signal to be analyzed was obtained, a Fast Fourier Transform (FFT) of the signal was computed (upper right of figure). This FFT, which transforms the data from the time domain to the frequency domain, identifies the modal response frequencies of the model. From the FFT plot the analyst selects the frequency of the mode to be analyzed. An expanded view of the FFT at the selected frequency is shown in the lower left of the figure. Discrete Fourier transforms at the frequency of interest are then made on successive blocks of data to calculate the decaying amplitude with time. A linear least-squares fit of the logarithm of the successive discrete Fourier transform amplitudes is then used to determine the slope of the data which is proportional to the damping value (lower right of figure).

Significance: The moving-block technique is set up as an interactive program giving the engineer a new tool to evaluate damping of models being tested in the TDT.

Future Plans: To improve the response time of the program through use of new graphical display devices and to improve capability by adding the ability to store plot files.

Figure 16 (a).

A SUBCRITICAL RESPONSE TECHNIQUE IMPLEMENTED ON THE MODCOMP DATA ACQUISITION SYSTEM AT TDT

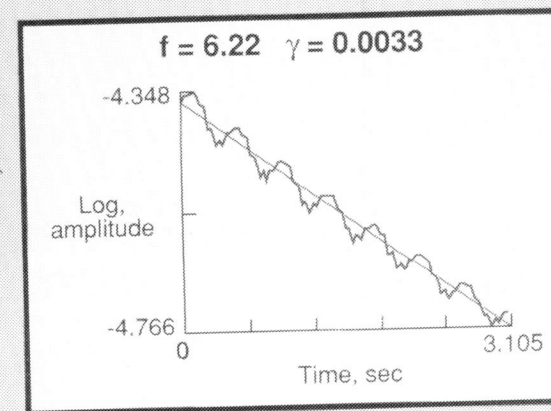
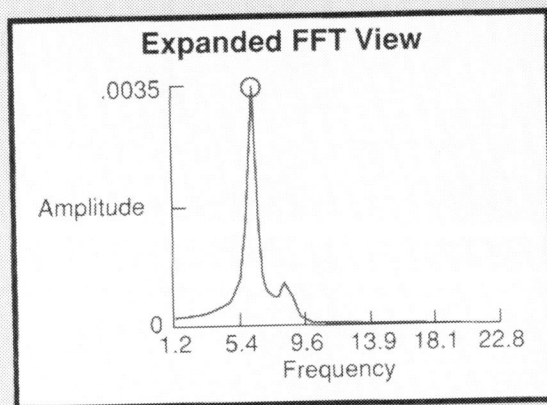
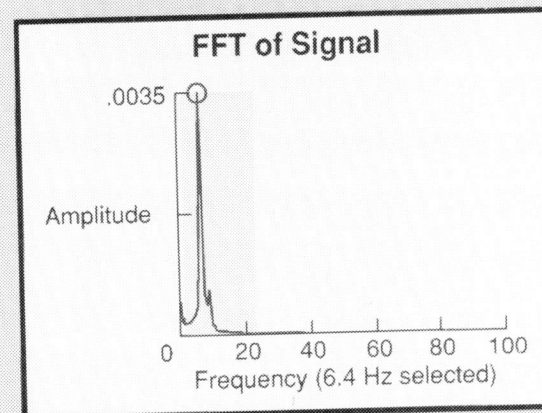
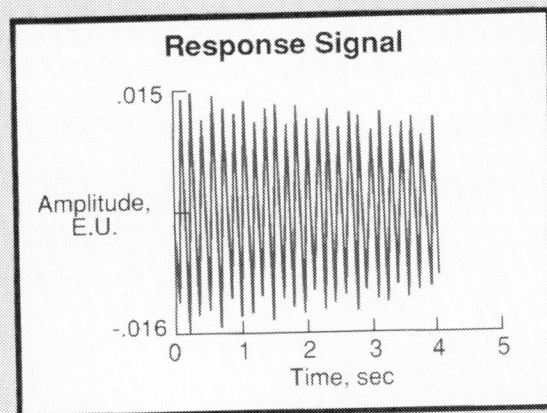
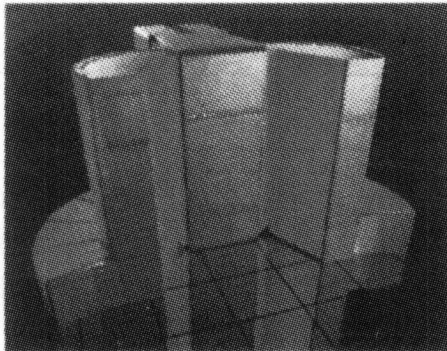


Figure 16 (b).

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UNSTEADY AERODYNAMICS BRANCH RESEARCH ACTIVITIES



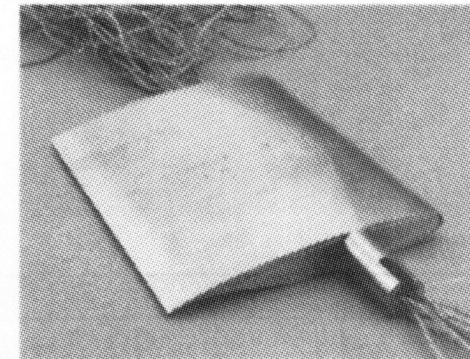
**Computational
Fluid Dynamics**



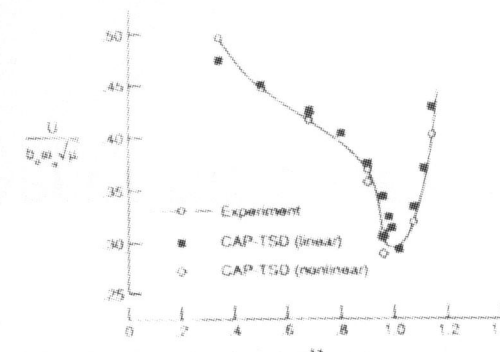
**Aircraft Aeroelastic
Analysis**



**Fluid Dynamics
Research**



**Code Validation
Experiments**



**Aeroelastic Code
Validation**

Figure 17.

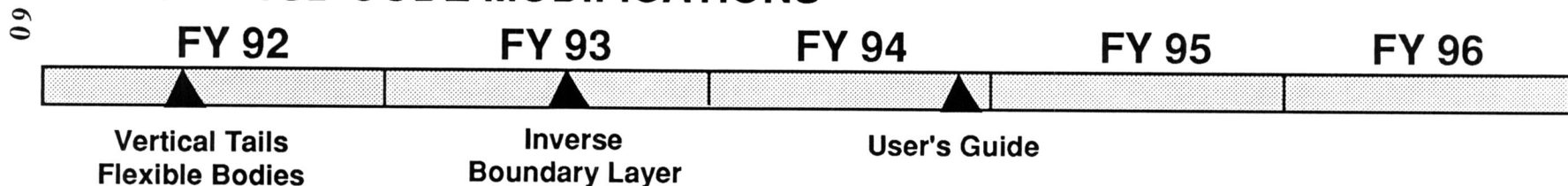
UNSTEADY AERODYNAMICS FUTURE PLANS (FY 92-96)

GOAL

COMPLETE DEVELOPMENT, VALIDATE, AND APPLY TSD CODE FOR
AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

● CAP-TSD CODE MODIFICATIONS



● CAP-TSD APPLICATIONS

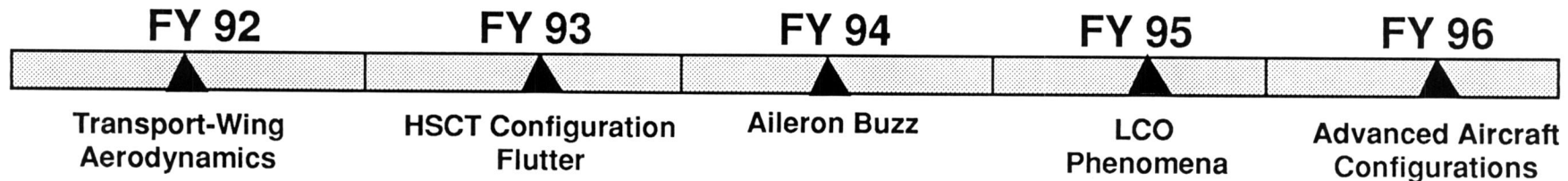


Figure 18 (a).

UNSTEADY AERODYNAMICS FUTURE PLANS (FY 92-96)

GOAL

DEVELOP, VALIDATE, AND APPLY STRUCTURED-GRID, EULER/
NAVIER-STOKES CODES FOR AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

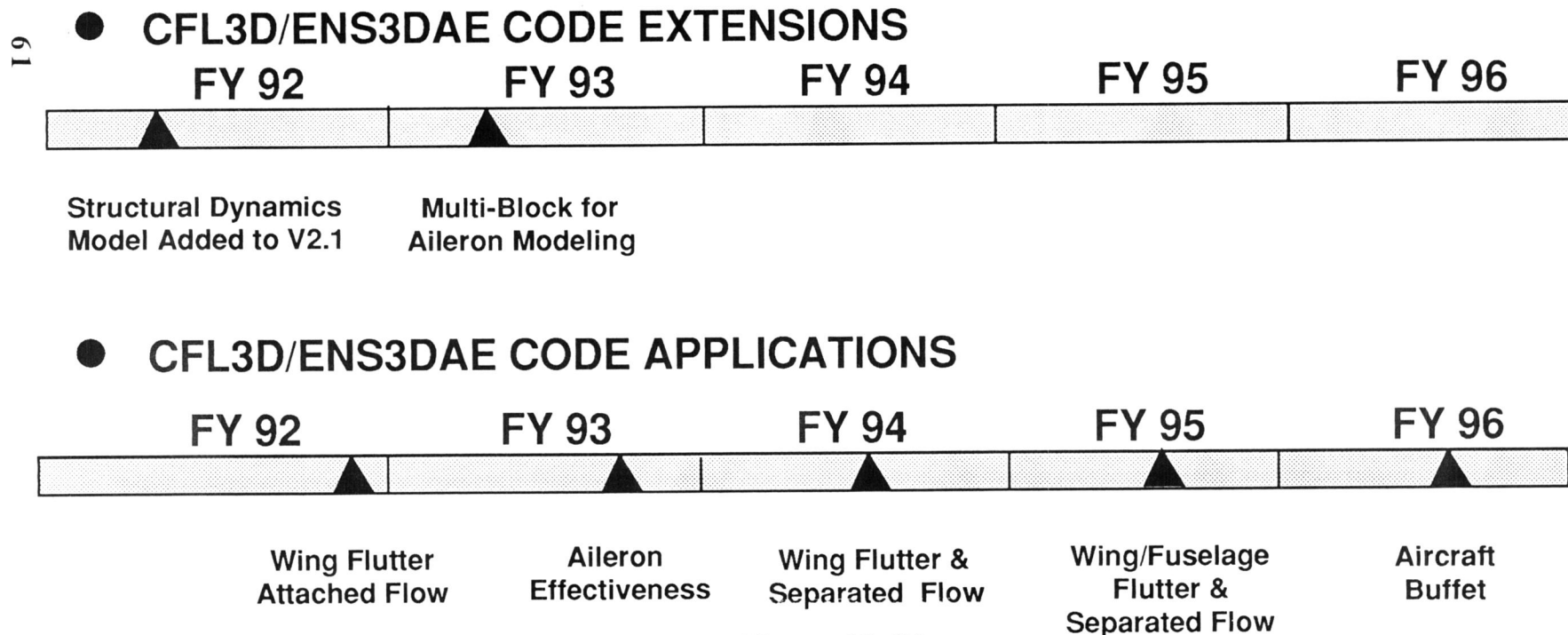


Figure 18 (b).

UNSTEADY AERODYNAMICS FUTURE PLANS (FY 92-96)

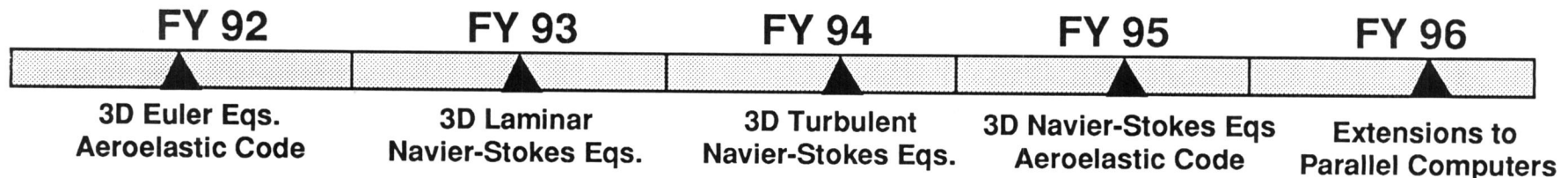
GOAL

DEVELOP, VALIDATE, AND APPLY UNSTRUCTURED-GRID EULER/
NAVIER-STOKES CODES FOR AIRCRAFT AEROELASTIC ANALYSIS

KEY OBJECTIVES

● CONTINUED CODE DEVELOPMENT

62



● CODE APPLICATIONS

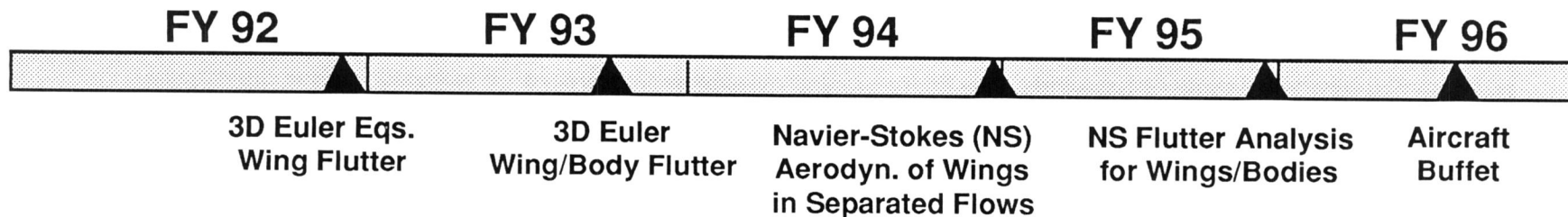


Figure 18 (c).

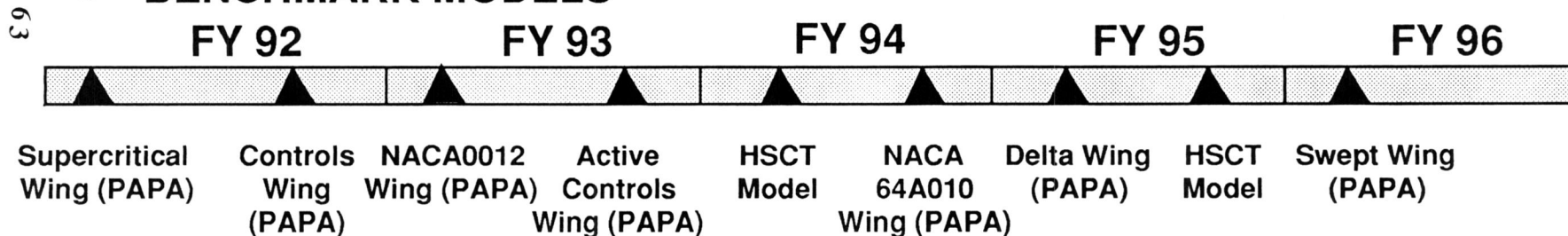
UNSTEADY AERODYNAMICS FUTURE PLANS (FY 92-96)

GOAL

SUPPORT DEVELOPMENT OF EXPERIMENTAL DATA BASES FOR
VALIDATION OF AERODYNAMIC / AEROELASTIC CFD CODES

KEY OBJECTIVES

● BENCHMARK MODELS



● UNIVERSITY / INDUSTRY

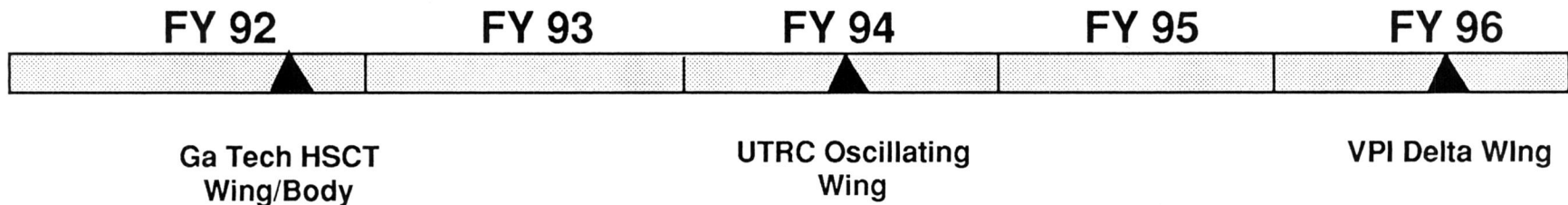


Figure 18 (d).

CAP-TSD EXTENDED TO TREAT FLEXIBLE VERTICAL SURFACE CONFIGURATIONS

Michael D. Gibbons
Lockheed Engineering and Sciences Company

RTOP 505-63-50

Research Objective: The objective of this research is to develop the capability to allow non-linear aeroelastic calculations on complete configurations which include swept flexible vertical tails/t-tail configurations.

Approach: The CAP-TSD (Computational Aeroelasticity Program - Transonic Small Disturbance) code previously could model rigid fuselage/bodies, rigid rectangular vertical tails, and flexible wings with an arbitrary planform. The major modifications that were made include: 1) the addition of terms to the TSD potential equation to account for swept shocks on the vertical surfaces, 2) devising a method to shear the grid vertically so that it conforms to the leading and trailing edges of swept tapered vertical surfaces, and 3) adding structural flexibility by computing the generalized aerodynamic forces for the vertical surfaces.

Accomplishment Description: All modifications necessary to treat general vertical surface configurations have been made to CAP-TSD. Calculations for a rectangular t-tail configuration oscillating in yaw at low subsonic speeds are shown in the figure along with comparisons with two linear theory results and experimental data. Specifically, the figure shows magnitude and phase for the horizontal stabilizer rolling moment coefficient. The CAP-TSD results compare well with linear theory and experimental data except for the phase in which CAP-TSD is in better agreement with experiment. Calculations for a swept t-tail configuration have also been performed.

Significance: The ability to treat flexible vertical surfaces with CAP-TSD allows for nonlinear aeroelastic studies to be conducted on more general configurations.

Future Plans: Further test cases are planned to validate fully the vertical surface modifications for nonlinear aeroelastic applications. Additional modifications to CAP-TSD will be made to allow treatment of a flexible fuselage.

Figure 19 (a)

CAP-TSD EXTENDED TO TREAT FLEXIBLE VERTICAL SURFACE CONFIGURATIONS

- Magnitude and Phase of the horizontal stabilizer rolling moment coefficient due to oscillatory yawing of a rectangular T-tail configuration

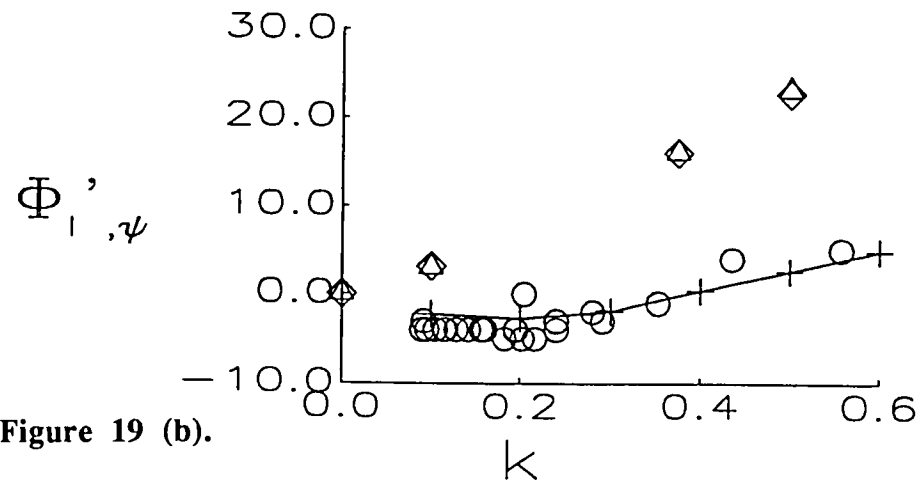
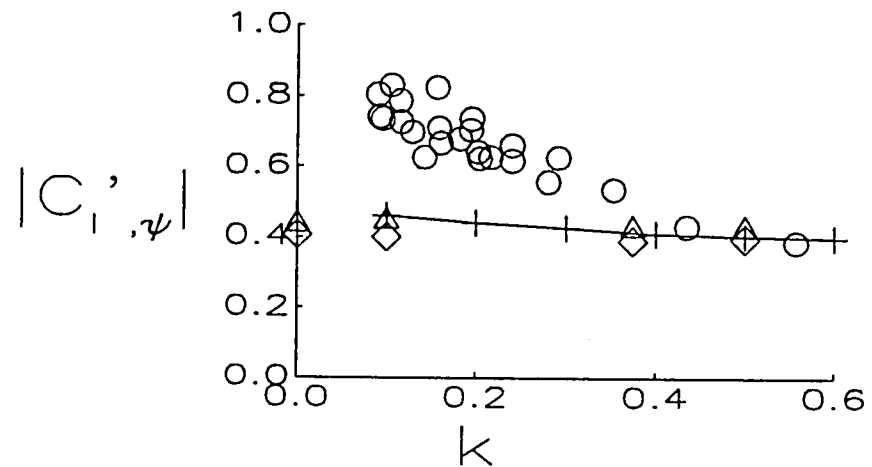
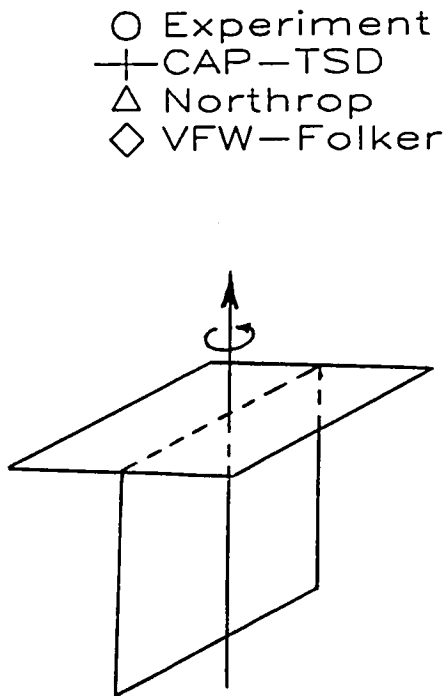


Figure 19 (b).

IMPROVED TRANSONIC FLUTTER PREDICTION OF AFW WIND-TUNNEL MODEL

Walter A. Silva and Robert M. Bennett
Unsteady Aerodynamics Branch

RTOP 505-63-21

Research Objective: Analytical predictions of the aeroelastic behavior of the Active Flexible Wing (AFW) wind-tunnel model were generated prior to flutter testing at NASA Langley's Transonic Dynamics Tunnel (TDT) (see photo). Although results compared well with some of the experimental flutter results, discrepancies were encountered for other cases. The objective of the present work, therefore, was to improve the analytical flutter predictions by refining several aspects of the computational model.

Approach: Prior to wind-tunnel testing, the first, or original, computational model of the AFW was developed for the CAP-TSD (Computational Aeroelasticity Program-Transonic Small Disturbance) transonic aeroelasticity code. Improvements to the original computational model were incorporated subsequently to investigate the sensitivity of the computed flutter boundary to these changes. The improvements included a corrected modeling of the wing tip ballast store, an improved structural model, and the use of vorticity and entropy corrections available in the CAP-TSD code.

99 **Accomplishment Description:** A comparison of flutter boundaries (Mach number versus dynamic pressure), for symmetric motions of the AFW, are shown in the figure for the original computational model, the latest computational model that includes all of the aforementioned improvements, and the experimental data. The original computational model indicated a rather severe transonic flutter dip, the bottom of which differed considerably from the bottom of the experimental transonic flutter dip as defined by the no-flutter track shown in the figure. The flutter boundary generated using the latest computational model, however, shows a significant improvement in the correlation with the experimental data in the transonic Mach number region, resulting in a more realistic transonic flutter dip. The discrepancy between the computational and experimental flutter results at subsonic conditions may be improved when further enhancements to the modeling of the wing tip ballast stores are available in the code.

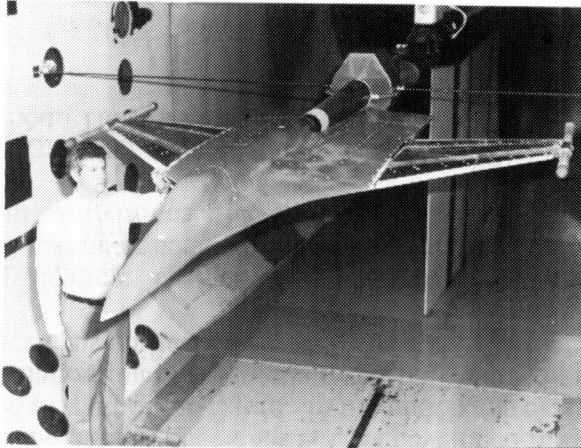
Significance: The study clearly demonstrates that accurate computational transonic flutter predictions using the CAP-TSD code are dependent on the accuracy of the computational model being investigated. The sensitivity of computed flutter boundaries to changes in the modeling should, therefore, be investigated and adequately addressed whenever possible.

Future Plans: These results will be presented at the Dynamic Specialists' Conference in Dallas, Texas in April of 1992. Analyses using an additional enhancement to the modeling of the wing tip ballast stores will be performed when that capability is available. Viscous effects will also be investigated when the viscous version of CAP-TSD is operational. A full-span computational model has been created and is currently being used for generating the flutter boundary due to antisymmetric motions of the AFW.

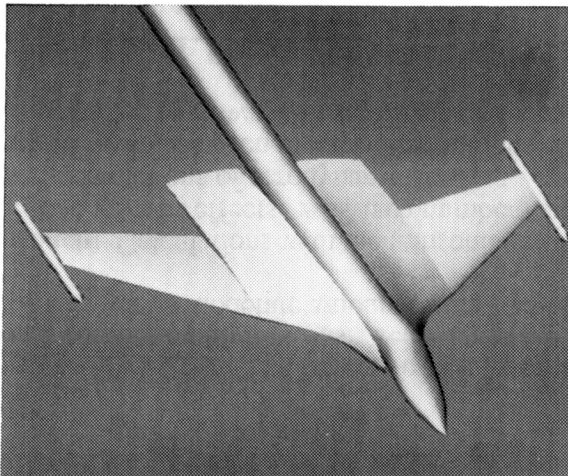
Figure 20 (a).

IMPROVED TRANSONIC FLUTTER PREDICTION OF AFW WIND-TUNNEL MODEL

- AFW model in TDT



- CAP-TSD computational model



- Computational refinements

- Corrected tip store modeling
- Updated structural model
- Vorticity and entropy corrections available in the CAP-TSD code

- Flutter boundaries

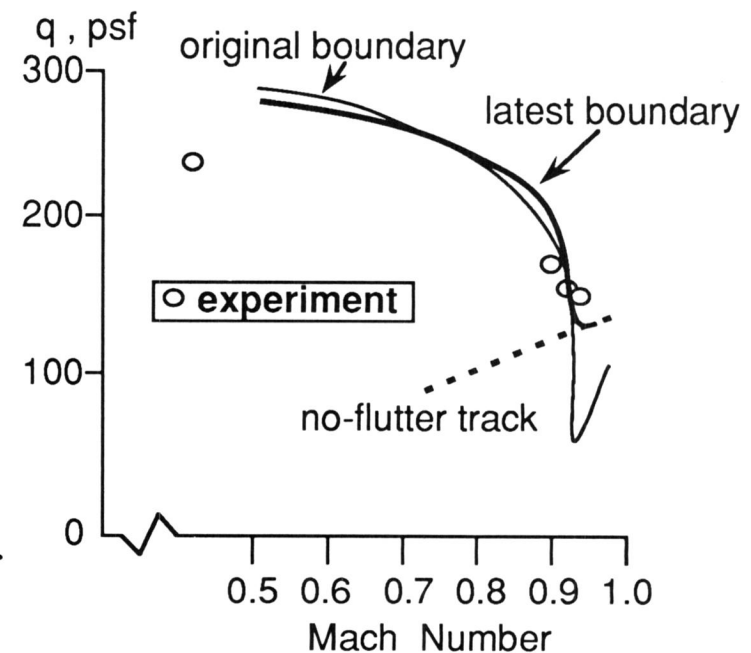


Figure 20 (b).

STRIP BOUNDARY LAYER IMPROVES STEADY AND UNSTEADY CAP-TSD RESULTS

James T. Howlett
Unsteady Aerodynamics Branch

RTOP 505-63-21

Research Objective: The objective of this research is to develop accurate and economical techniques for predicting unsteady transonic airloads for 3-D configurations. Techniques are sought which are capable of calculating flows with significant viscous effects, including flow fields with a moderate amount of unsteady flow separation and reattachment.

Approach: Calculations with the transonic small disturbance potential computer code CAP-TSD have been quite accurate for flows with negligible viscous effects. As Mach numbers increase, shock waves increase in strength and viscous effects must be included for accurate predictions of aerodynamic loading. An interactive strip boundary layer method which includes an inverse calculation for mildly separated flows has been incorporated into the code. With the inclusion of this boundary layer technique, the CAP-TSD computer code may be applied to flows with significant viscous effects, including flows with mild amounts of separation.

Accomplishment Description: The CAP-TSD computer code with viscous corrections has been applied to calculate steady and unsteady pressure distributions on the F-5 wing at a Mach number of $M = 0.9$ and an angle of attack of $\alpha = 0^\circ$. The upper surface steady pressure distributions at two stations near midspan ($\eta=0.512$ and 0.641) shown on the left part of the figure indicate significant viscous effects in the midchord regions. Specifically the inviscid results show a mild shock, whereas the viscous results and the experiment indicate that the shock has not yet developed fully. The corresponding unsteady pressure distributions (first harmonics) are shown on the right part of the figure. In the midchord region, the unsteady viscous results have significantly lower amplitudes than the inviscid calculations and the viscous shock pulses are slightly upstream of their inviscid counterparts. Both the steady and unsteady comparisons indicate a significant improvement in the calculated pressures due to the inclusion of viscous effects.

Significance: The good agreement between the experimental results and the CAP-TSD viscous calculations indicates that the CAP-TSD computer code with viscous corrections can be used for accurate predictions of aerodynamic loads on 3-D configurations with significant viscous effects. As a result, the range of applicability of the CAP-TSD computer code is significantly extended.

Future Plans: Applications of the CAP-TSD viscous computer code are underway to determine the limits of validity of the improved method. These applications will include 3-D configurations with moderate amounts of flow separation.

Figure 21 (a).

STRIP BOUNDARY LAYER IMPROVES STEADY AND UNSTEADY CAP-TSD RESULTS

$M = 0.9$ $\alpha = 0$ deg $k = 0.137$

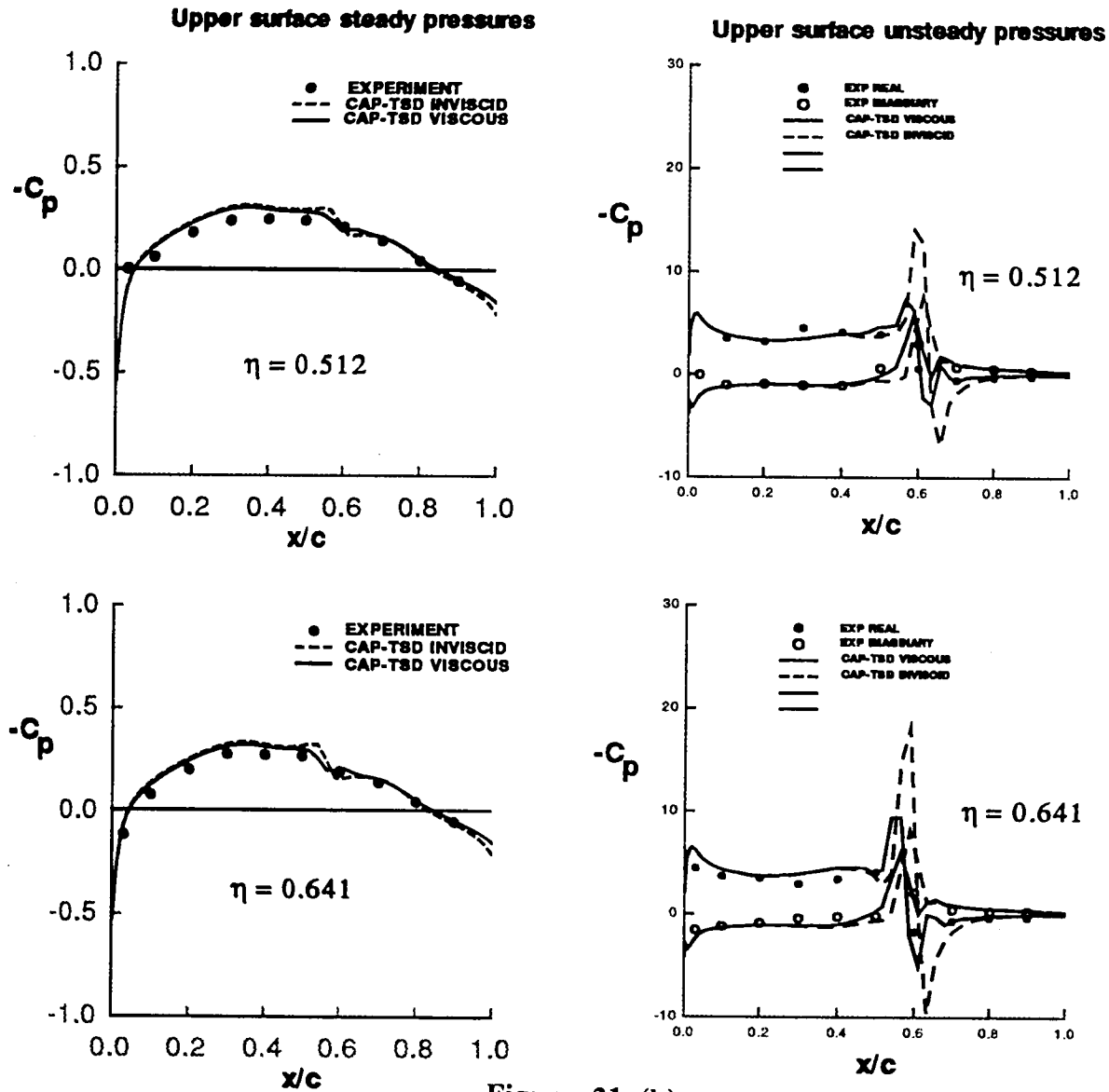


Figure 21 (b).

EFFECTS OF AIRFOIL PITCH OSCILLATION FREQUENCY IN TRANSONIC SMALL DISTURBANCE THEORY CALCULATIONS

Samuel R. Bland
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective is to provide better numerical treatment of the unsteady wave propagations which occur in unsteady transonic flow.

Approach: The CAP-TSD (Computational Aeroelasticity Program - Transonic Small Disturbance) computer code is used to study shock and other wave formation and propagation in unsteady transonic flow. Workstations now possess sufficient memory and speed for computation of two-dimensional airfoil motions. Color graphics provide for real-time animated presentation of wave motion which serves to enhance understanding of the computational problems in ways which were not possible before.

Accomplishment Description: Results are shown for the NACA 0012 airfoil oscillating in pitch with amplitude of 2.5 degrees for three frequencies at Mach number 0.8. A mesh of 5040 points was used with 100 points on the airfoil. The calculation and display of the results requires about one second per time step. The time history of the upper surface chordwise pressure distribution is shown at a sequence of 64 points during one cycle of motion. Time increases from top to bottom in each part of the figure; the cycle begins at the upper right and ends at the lower left with the return of the pressure to its starting values.

The figure on the left is for a moderate reduced frequency of $k = 0.16$. The shock wave moves over about 25 percent of the chord in an apparently sinusoidal fashion. There is a large phase difference between the shock position and airfoil motion; the shock is at its most rearward position after the airfoil passes through its mean position on the downward stroke at the middle of the time history. The center figure is for $k = 0.08$, half that of the previous value. In this case the shock wave becomes quite weak as it moves forward toward the leading edge during the latter part of the oscillation cycle. A small wavelet develops just aft of the shock. The final figure is for a low frequency of $k = 0.04$. Here the shock wave travels over about 40 percent of the chord and disappears near the end of the cycle as it nears the leading edge. Several small oscillations develop as the shock disappears, the local flow Mach number approaches unity, and the wave propagation speed nears zero. For these conditions disturbances, which appear as small wavelets, tend to remain trapped where they form.

Significance: The availability of high performance computer workstations permits a much deeper appreciation of the nature of the problems which must be solved to provide accurate unsteady aerodynamics for use in aeroelastic calculations.

Future Plans: Detailed study of the computed flow will be used to improve the numerical treatment of shock and other wave motions in TSD theory.

Figure 22 (a).

EFFECTS OF AIRFOIL PITCH OSCILLATION FREQUENCY IN TRANSONIC SMALL DISTURBANCE THEORY CALCULATIONS

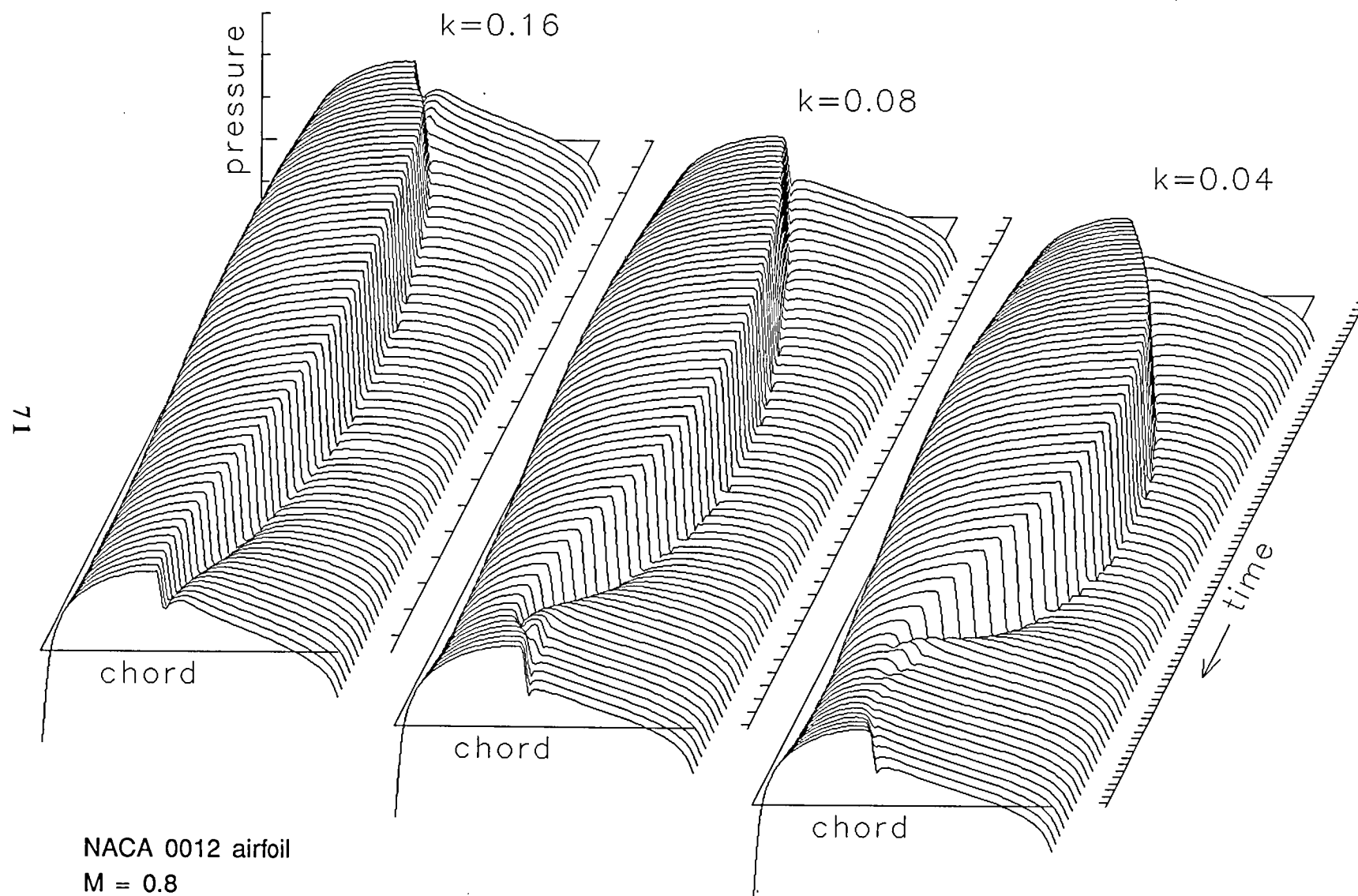


Figure 22 (b).

IMPLICIT UPWIND EULER ALGORITHM BASED ON UNSTRUCTURED DYNAMIC MESHES DEMONSTRATED FOR COMPLEX AIRCRAFT CONFIGURATION

John T. Batina
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of this research was to demonstrate an implicit upwind algorithm for the numerical solution of the time-dependent Euler equations through application to a complex aircraft configuration. The algorithm has been applied previously to the ONERA M6 wing to predict steady flow at transonic conditions. These results compared well with experimental data and, therefore, the next step in the validation of the algorithm is performing applications for more complicated configurations.

72 **Approach:** The algorithm, which was developed within the Unsteady Aerodynamics Branch, involves accurate and efficient spatial and temporal discretizations of the Euler equations, based on unstructured meshes of tetrahedral grid cells. The spatial discretization involves an upwind approach which accounts for the local wave-propagation characteristics of the flow and captures shock waves sharply with at most one grid point within the shock structure. The upwind discretization is naturally dissipative and consequently does not require additional artificial dissipation terms or the adjustment of free parameters to control the dissipation. Furthermore, the temporal discretization is an implicit time-integration scheme involving a Gauss-Seidel relaxation procedure. The scheme allows the selection of the step size based on the temporal accuracy dictated by the physical problem being considered, rather than on the numerical stability of the algorithm. Consequently, very large time steps may be used for rapid convergence to steady state, and an appropriate step size may be selected for unsteady cases, independent of numerical stability issues.

Accomplishment Description: To demonstrate the implicit upwind algorithm, calculations were performed for the Boeing 747 aircraft. The results were obtained using the unstructured mesh shown in the left part of the figure. The 747 geometry includes the fuselage, the wing, horizontal and vertical tails, under-wing pylons, and flow-through engine nacelles. The unstructured mesh for the 747 contains 101,475 tetrahedra and 19,055 nodes for the half-span airplane. Steady-state calculations were performed for the aircraft at $M_\infty=0.84$ and $\alpha=2.73^\circ$. The resulting steady pressure coefficient contours on the surface of the 747 aircraft are shown in the right part of the figure. The contours indicate that there is a significant amount of flow compression on the nose of the aircraft, along the inboard leading edge of the wing, and inside the cowl of the engine nacelle. There is flow expansion on the forward fuselage, on the horizontal and vertical tail surfaces, and on the upper surface of the wing terminated by a shock wave.

Significance: The solution required less than one hour of CPU time on a Cray-2 computer which is an order of magnitude less time than required by previous methods.

64 **Future Plans:** The accuracy as well as efficiency of the new implicit upwind algorithm will be determined more completely through additional applications.

Figure 23 (a).

IMPLICIT UPWIND EULER ALGORITHM BASED ON UNSTRUCTURED DYNAMIC MESHES DEMONSTRATED FOR COMPLEX AIRCRAFT CONFIGURATION

- Tetrahedral mesh
 - 19,055 nodes
 - 101,475 cells
- Pressure contours
 - $M_\infty = 0.84$ and $\alpha = 2.73^\circ$
 - 1 hour CPU time (Cray-2)

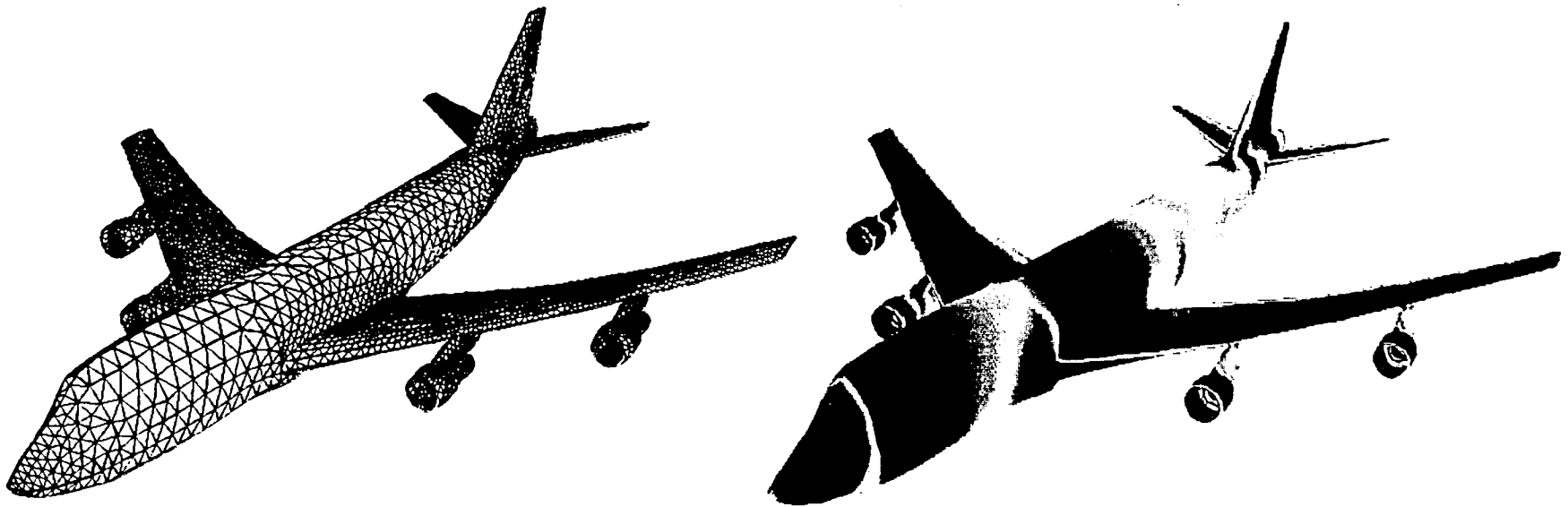


Figure 23 (b).

SPATIAL ADAPTATION PROCEDURE VERIFIED FOR UNSTEADY AIRFOIL ANALYSIS

Russ D. Rausch
Purdue University
and
John T. Batina
Unsteady Aerodynamics Branch

RTOP 505-63-50

Research Objective: The objective of the research is to apply an automated spatial adaptation procedure for the accurate and efficient computation of unsteady flows about oscillating airfoils.

Approach: Modifications were made to a two-dimensional unstructured-grid upwind-type Euler code to include procedures for mesh enrichment and mesh coarsening to either add points in high gradient regions of the flow or remove points where they are not needed, respectively, to produce solutions of high spatial accuracy at minimal computational cost. The modifications include a parametric spline routine to locate new points that lie on boundaries. The advantage of using a spatial adaptation procedure is that the solution dictates the mesh topology for an efficient computation.

74 **Accomplishment Description:** Calculations were performed for a NACA 0012 airfoil pitching in forced harmonic motion with an amplitude of $\alpha_1 = 2.51^\circ$ at $M_\infty = 0.755$ and $\alpha_0 = 0.016^\circ$ for three complete cycles of motion. The problem was selected to demonstrate the adaptation procedure on a moving mesh. Computed density contours are shown in the middle part of the figure at three instants in time during the third cycle. The density contours give a reasonable representation of the shock motion during the first part of the cycle where the shock moves from the lower surface to near the mid-chord on the upper surface. The corresponding instantaneous meshes are shown in the lower part of the figure and clearly indicate the enrichment in regions near shock waves and near the stagnation points. They also show coarsened regions where previously enriched regions have relatively small flow gradients. The upper right part of the figure shows the variation of the number of cells or triangles in the mesh throughout the third cycle. Since the number of cells in the mesh is a measure of the computational cost per time-step, the spatial adaptation procedure allows for an efficient computation by using the minimum number of cells required for a given spatial resolution.

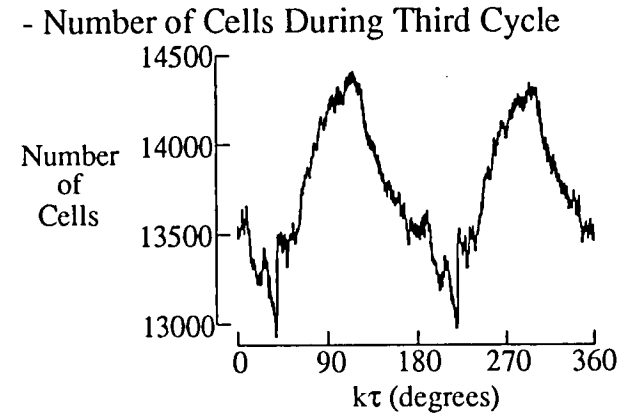
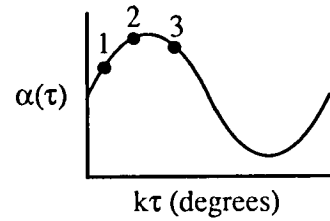
Significance: The results demonstrate the ability of the automated spatial adaption procedure to add and remove points during an unsteady flow computation to accurately and efficiently resolve transient flow features on a moving mesh.

Future Plans: Plans are to develop mesh enrichment and mesh coarsening procedures for a three-dimensional unstructured-grid upwind-type Euler code to be used for unsteady aerodynamic and aeroelastic analyses of complete aircraft configurations.

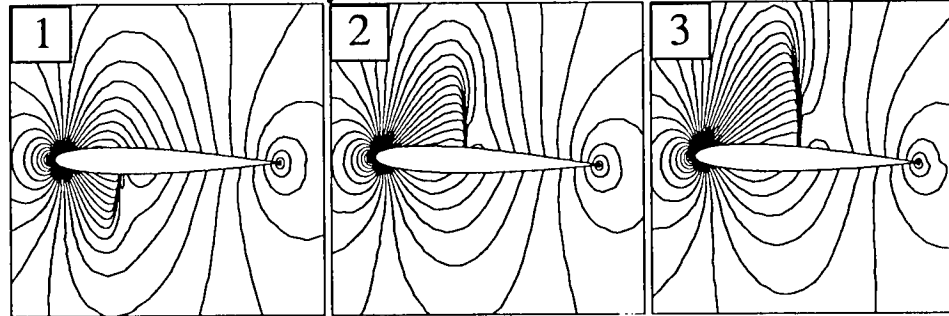
Figure 24 (a).

SPATIAL ADAPTATION PROCEDURE VERIFIED FOR UNSTEADY AIRFOIL ANALYSIS

- NACA 0012 Airfoil
- $M_\infty=0.755$, $\alpha_0=0.016^\circ$, $\alpha_1=2.51^\circ$, $k=0.0814$



- Instantaneous Density Contours



- Instantaneous Meshes

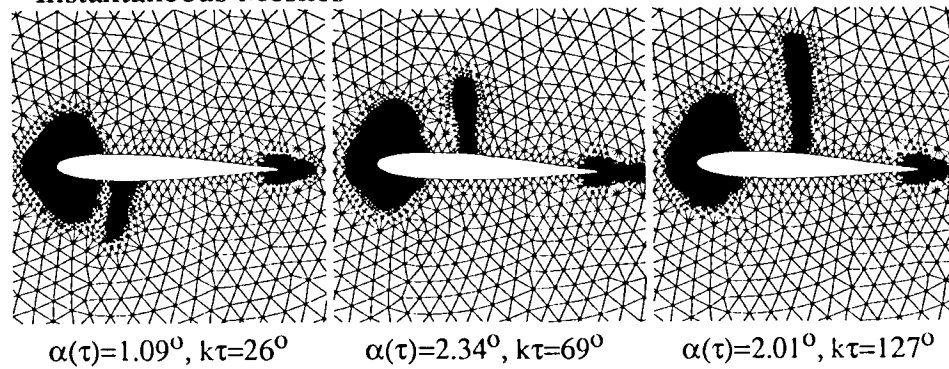


Figure 24 (b).

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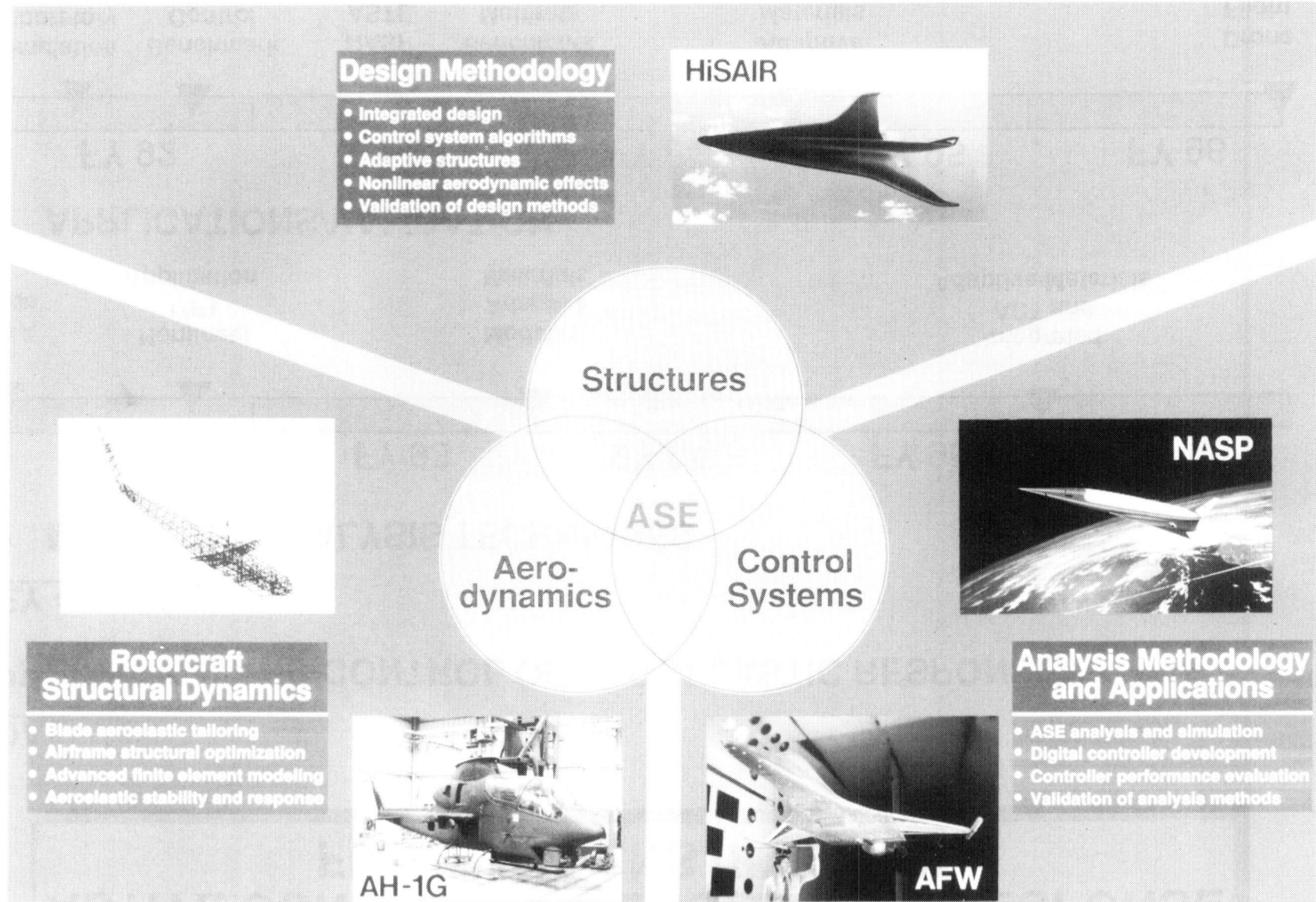


Figure 25.

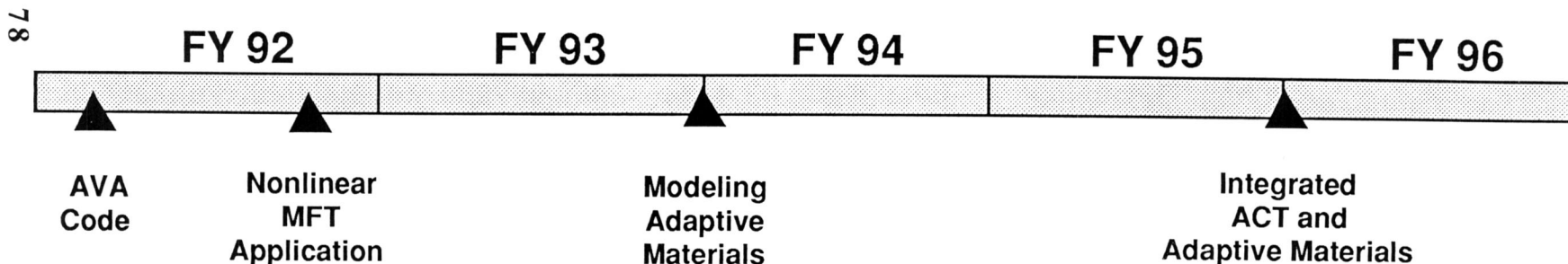
ACTIVE CONTROL OF AEROELASTIC RESPONSE FUTURE PLANS (FY 92-96)

GOAL

PREDICTION AND CONTROL OF AEROELASTIC RESPONSE

KEY OBJECTIVES

● MODELING/ANALYSIS TECHNIQUES



● APPLICATIONS/VALIDATION

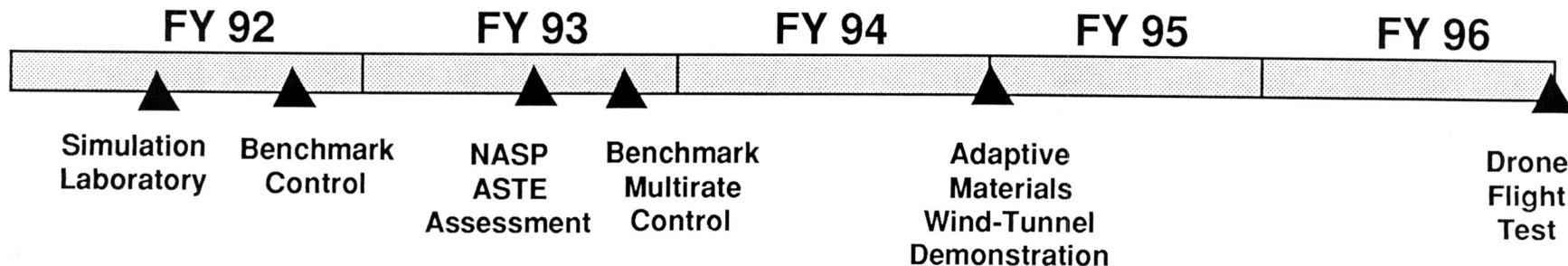


Figure 26 (a).

ACTIVE CONTROL OF AEROELASTIC RESPONSE FUTURE PLANS (FY 92-96)

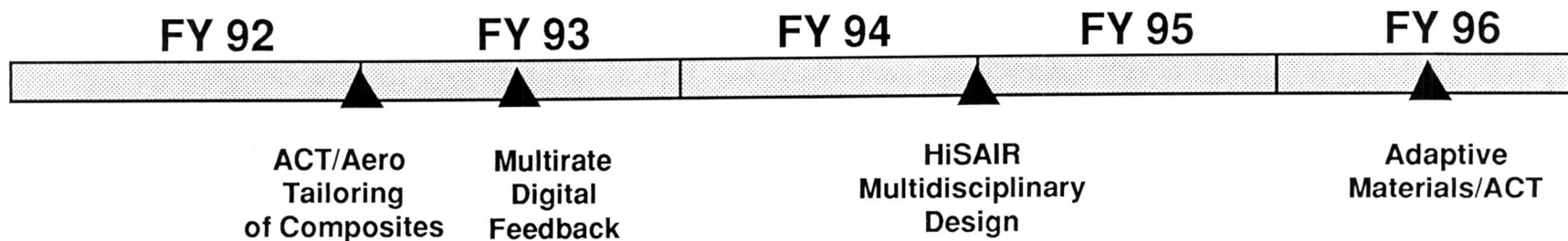
GOAL

ADVANCED SYNTHESIS METHODOLOGY

KEY OBJECTIVES

79

● INTEGRATED MULTIDISCIPLINARY DESIGN



● DESIGN ALGORITHMS

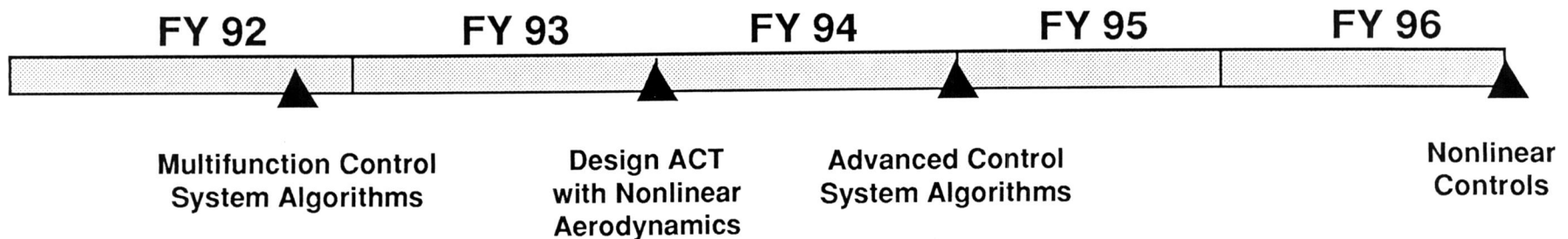


Figure 26 (b).

CAPABILITY DEVELOPED FOR BASIC AEROELASTIC ANALYSES AND SUPPORT OF DESIGN OPTIMIZATION

Thomas A. Zeiler
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RTOP 505-63-50

Objective: The objective of this work is to develop an aeroelastic analysis tool that can perform a variety of basic aeroelastic analyses and compute design sensitivities of the results of these analyses so that a design optimization procedure can use the analysis results as design constraint functions with analytical gradients. The primary application of the tool is intended to be in the High Speed Airframe Integration Research (HiSAIR) program. A secondary objective of the work is to provide the Aeroservoelasticity Branch (ASEB) with readily useable tool for basic aeroelastic analyses.

Approach: The Aeroelastic Vehicle Analysis (AVA) package was developed as an assembly of separate FORTRAN main programs with subroutines that have been written or altered to use or produce data compatible with other parts of the package. The initial thrust was to enhance the capabilities and streamline operational aspects of the main analysis program, FASTEX, the flutter and divergence analysis portion of the synthesis program, FASTOP. Supporting subroutines and main programs were added as needed.

08 **Accomplishment Description:** FASTEX came to ASEB with the capability for subsonic doublet lattice aerodynamics, and flutter and divergence analysis. The program was altered to include both Piston Theory aerodynamics for hypersonic flow and a version of the ZONA program low supersonic aerodynamic data. Changes to pressure coefficients for selected aerodynamic boxes and vibration modes can be made for all sources of aerodynamic data. Rigid and flexible values of steady and unsteady stability and control derivatives, and values of aerodynamic load resultant (shear force, and bending and torsion moments) coefficients at a load station can be calculated. Design sensitivities of flutter, divergence, and control reversal speeds, as well as sensitivities of the stability and control derivatives can also be calculated. Modal data can be accepted from the ELAPS (Equivalent Laminated Plate System) and EAL (Engineering Analysis Language) structural analysis programs. Another program collates the results and sensitivities of numerous analyses into a master file for use by an optimization program. Translator programs convert ELAPS modal data for use by CAP-TSD (Computational Aeroelasticity Program - Transonic Small Disturbance) and ISAC (Integration of Structures, Aerodynamics, and Controls). Aerodynamic influence coefficients and generalized aerodynamic forces (GAFs) for both doublet lattice and ZONA can be saved and reused, allowing significant time savings for repetitive calculations.

Significance: AVA has been used in a variety of efforts in ASEB. In addition to its use in HiSAIR, AVA has been used in support of the National AeroSpace Plane (NASP) Government Work Package 75, Piezoelectric Flutter Suppression research, and for a one-time analysis of STS orbiter vertical tail loads requested by the Aerospace Safety Advisory Panel.

Future Plans: AVA will be an evolving analysis tool as users suggest improvements. Planned enhancements include simple s-plane fits of GAFs and of unsteady aerodynamic load resultants for dynamic loads analyses, and the ability to read modal data from NASTRAN. Also, a User Guide will be updated and maintained as needed.

Figure 27 (a).

CAPABILITY DEVELOPED FOR BASIC AEROELASTIC ANALYSES AND SUPPORT OF DESIGN OPTIMIZATION

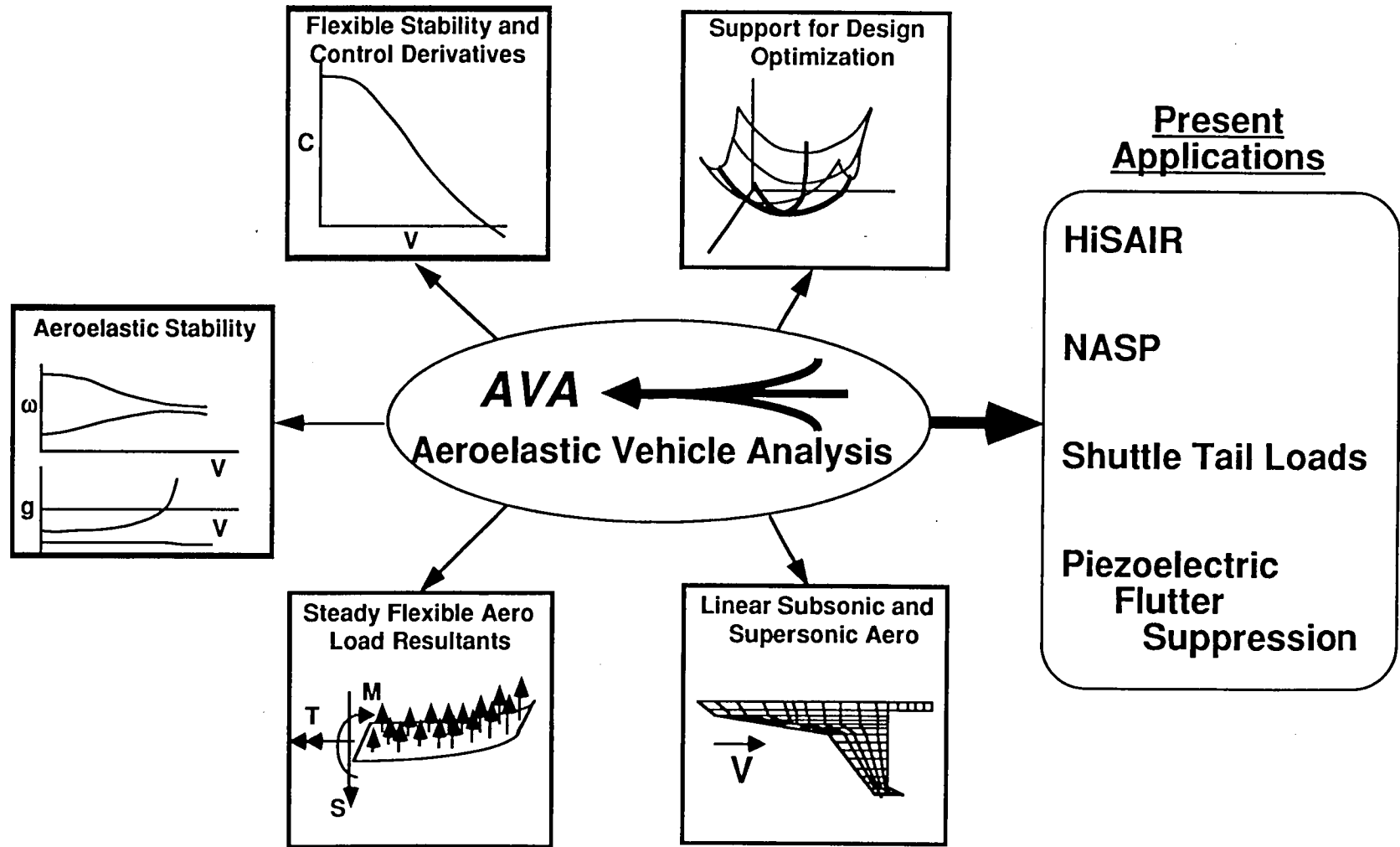


Figure 27 (b).

TWO SCHEMES FOR DETERMINING MAXIMUM GUST LOADS FOR AIRCRAFT WITH NONLINEAR CONTROLS DEMONSTRATED

Robert C. Scott and Boyd Perry III
Aeroservoelasticity Branch

Anthony S. Pototzky
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RTOP 505-63-50

Research Objective: The objective of this activity is to develop and demonstrate a matched-filter based scheme for obtaining maximized and time-correlated gust loads for nonlinear flexible aircraft.

Approach: In its original form, the matched-filter method offers a means of computing maximized and time-correlated gust loads for linear aircraft only. The approach is to extend this method to nonlinear aircraft using constrained optimization applied to the excitation waveform. Nonlinearities consist of limits on control surface deflections.

Accomplishment Description: Two schemes (a one-dimensional search and a multi-dimensional search) have been developed and demonstrated on a nonlinear aeroservoelastic model of a flexible aircraft. For the one-dimensional search, the strength (k) of an initial impulse is varied to find an excitation waveform which yields a maximum load value. For the multi-dimensional search, a constrained optimization scheme is applied which uses the excitation waveform obtained from the one-dimensional search as a starting point and alters the shape of that waveform to further maximize the load. The accompanying figure presents results from both schemes. Results for the one-dimensional search are shown in the upper two figures. The upper left plot shows three excitation waveforms obtained from three impulse magnitudes k_1 , k_2 , and k_3 . The upper right plot shows the load time histories which result from these three excitation waveforms. Notice that the peak values vary as a function of k . Results for the multi-dimensional search are shown in the lower two plots. The lower left plot shows the initial excitation waveform (same as k_1 in the one-dimensional search) and the optimized excitation waveform. The lower right plot shows the load time histories which result from these two waveforms and points out the peak values. The center plot summarizes and compares the results from the two schemes. The solid dots represent the peak values from the one-dimensional search; the circles, those from the multi-dimensional search. This figure demonstrates two important results and implies a third: (1) the answer obtained from the multi-dimensional search is independent of the starting point and appears to be the global maximum; (2) the answer from the one-dimensional search is within 1% of the optimized answer; and (3) because the multi-dimensional search is computationally expensive, the one-dimensional search may be a practical compromise between expense and quality of answers

Significance: Modern transport aircraft employ active control systems which almost always contain significant hardware and software nonlinearities. Since most of the established methods used to calculate aircraft gust loads are applicable to linear systems only, the current nonlinear schemes demonstrate effective means for obtaining the maximized and time-correlated gust loads for modern transport aircraft.

Future Plans: Analyses of more complex and realistic systems are planned. The results will be presented in April 1992 in Dallas at the Gust Specialist Meeting and at the AIAA Structures, Structural Dynamics, and Materials Conference. An abstract will be submitted to the AIAA AFM Conference, to be held in August 1992.

Figure 28 (a).

TWO SCHEMES FOR DETERMINING MAXIMUM GUST LOADS FOR AIRCRAFT WITH NONLINEAR CONTROLS DEMONSTRATED

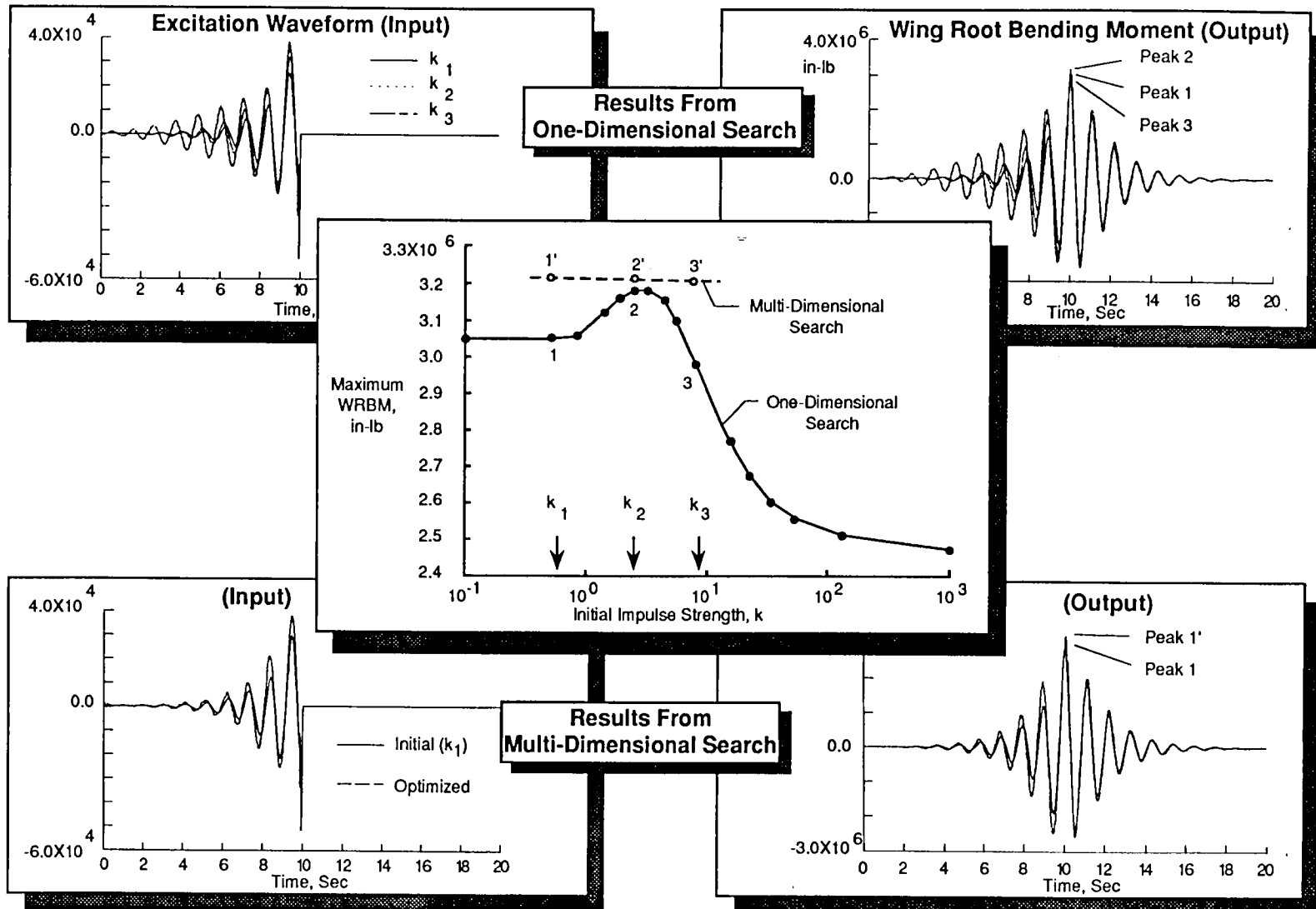


Figure 28 (b).

TIME SIMULATION OF FLUTTER WITH LARGE, RAPID STIFFNESS CHANGES

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Technion-Israel Institute of Technology

Carol D. Wieseman
Aeroservoelasticity Branch

RTOP 505-50-63

Research Objective: The Active Flexible Wing (AFW) wind-tunnel model is equipped with a wing-tip ballast store designed specifically to cause flutter within the limits of the Transonic Dynamics Tunnel envelope and as a flutter stopper device. The tip ballast is attached to the wing of the model by a brake mechanism (decoupler device). When the brake is on, the tip ballast is rigidly attached to the wing tip and the store mass and inertia are "coupled" with the wing dynamics; when the brake is off, the ballast is flexibly attached to the wing and the store dynamics are "decoupled" from the wing dynamics. The objective of this effort is to develop a methodology for performing a time simulation of the model response as the mechanism is engaged to investigate the wind-tunnel model behavior and to assure its safety.

Approach: Free-free vibration modes are first calculated for a nominal AFW finite-element model loaded with relatively large fictitious masses located in the area of the structural variations. These modes and the associated oscillatory aerodynamic force matrices are used to construct a time-domain model for the "coupled" aeroelastic case (fictitious mass contribution to the generalized mass matrix is removed). The "decoupled" aeroelastic model is obtained by simply introducing stiffness and damping coupling terms that represent the variation in the structural properties. Time simulation of the AFW model response prior to engaging the decoupler mechanism is accomplished by using the "coupled" model and its output equations. At the point transition occurs, the simulation of the "decoupled" model begins using the final conditions of the "coupled" case as initial conditions and the system and output equations of the "decoupled" model.

Accomplishment Description: The modeling procedure has been verified by calculating the time responses of the AFW model to a specified initial condition. This was accomplished by comparing displacements, rates, and accelerations at several locations on the tip ballast and on the wing using the math models described above to similar data calculated using conventionally developed "coupled" and "decoupled" math models. Once the modeling procedures were verified, a simulation of the rapid structural change resulting from engaging the decoupler mechanism was performed. The upper right figure shows the time history of the acceleration at a point near the forward end of the tip ballast. The lower right figure shows the time history at the same location, but on an expanded scale to better show the history just before transition and shortly afterwards. In the case of the figure shown the transition from coupled to decoupled conditions was instantaneous and occurred near 20 seconds.

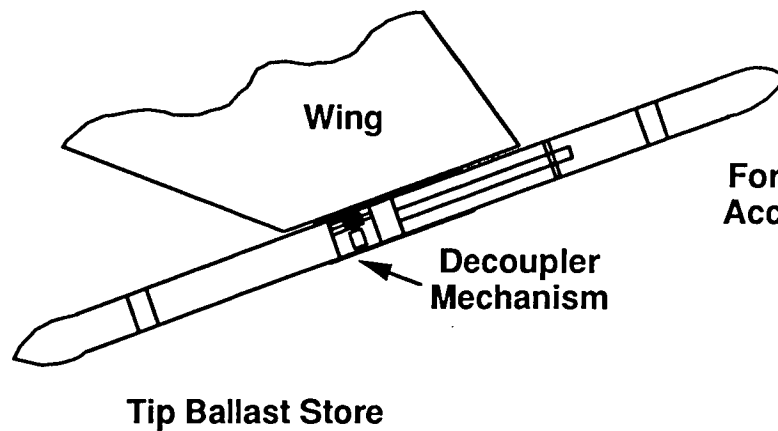
Significance: These time simulations provided information to assess the AFW model behavior during transition. The techniques developed can be used to investigate aircraft stability for rapid changes in mass and stiffness resulting from releasing weapons, battle damage, structural failure, etc.

Future Plans: The results of this study will be presented in April 1992 in Dallas at the AIAA Structures, Structural Dynamics, and Materials Conference. Future plans include incorporating the method in multidisciplinary optimization schemes.

Figure 29 (a).

TIME SIMULATION OF FLUTTER WITH LARGE, RAPID STIFFNESS CHANGES

85



- Tip Ballast Store "Rigidly" Attached to Wing for Coupled Conditions
- Tip Ballast Store "Flexibly" Attached to Wing for Decoupled Conditions

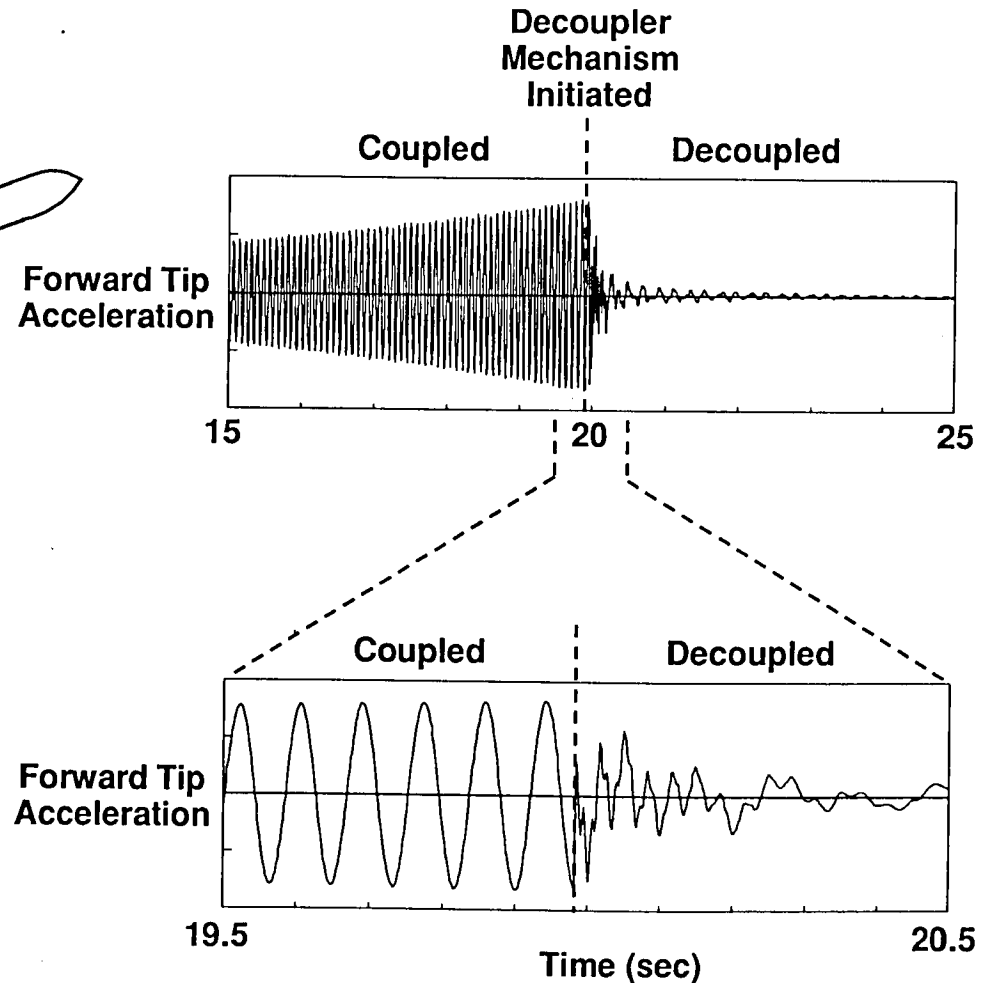


Figure 29 (b).

CONTROL EFFECTIVENESS LIMIT DEFINED FOR PIEZOELECTRIC ACTUATORS ON FULL SCALE AIRCRAFT

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Purdue University

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Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: As a continuation of research into the use of piezoelectric materials as actuators to control the static aeroelastic response of wing structures, a study was undertaken to evaluate how effective such materials would be in actuating full-scale aircraft. No research prior to this indicates whether these materials may be effectively used in other than small scale models of aircraft wings.

Approach: The present study addressed the use of piezoelectric materials for static aeroelastic control of both unswept and swept wing configurations. That accompanying figure provides some of the unswept wing results. In the upper left hand side of the figure, a schematic of the airfoil section is shown. The sketch shows an imbedded piezoelectric actuator of thickness $2t_a$ and width w , and a feedback control system. In principle, a voltage field, proportional to a measured wing root strain, is applied across the piezoelectric material to deform the airfoil. This deformation and the associated change in the aerodynamic forces provides, in theory, static aeroelastic control of the wing. For this study equations have been developed that relate the control effectiveness of the piezoelectric actuator to changes in aircraft scale and to changes in wing loading, for example, increases in weight due to additional passengers, cargo, fuel, etc.

Accomplishment Description: A change from model scale to full scale or an increase in weight of the full-scale aircraft increases wing loading. The results of this investigation indicate that the effectiveness of a piezoelectric actuator for static aeroelastic control is tied closely with wing loading. The performance of a piezoelectric actuator is limited by its dimensions and by the voltage across the material. For constant width and spanwise dimensions the lower right figure shows that with increases in wing loading, thicker actuators are required to obtain an equivalent level of control over the static aeroelastic response of a wing. The upper limit on actuator thickness occurs when the piezoelectric material exceeds the space available within the airfoil shape (for this case, thickness h). Increasing the voltage field also increases the performance of the material, but there is an upper limit on the voltage to prevent damage to the material. Thus, the requirements for piezoelectric materials as actuators increase and may become limited as wing loading increases. Although the unswept wing results were determined to be independent of dynamic pressure, the use of piezoelectric actuators on swept wing configurations are a function of dynamic pressure which may further limit their usefulness.

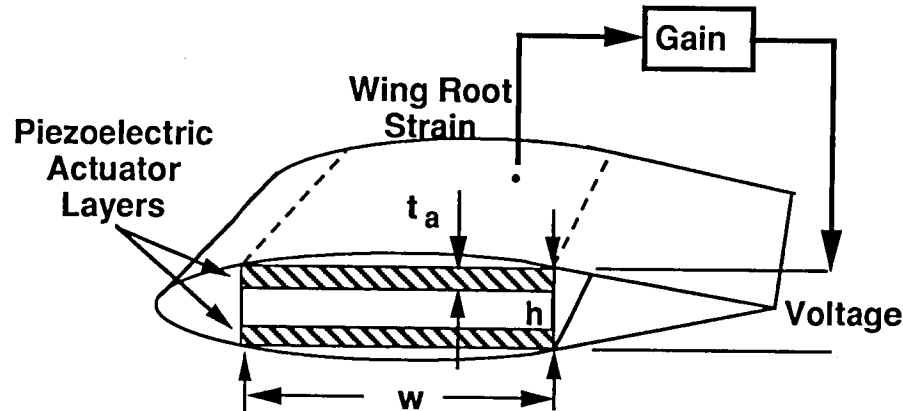
Significance of Research: The conclusion of this study is, then, that piezoelectric materials with more advanced mechanical properties must be developed in order to make piezoelectric actuators viable for use on full size aircraft.

Future Plans: Research into the use of piezoelectric materials as aircraft actuators will continue under this grant.

Figure 30 (a).

CONTROL EFFECTIVENESS LIMIT DEFINED FOR PIEZOELECTRIC ACTUATORS ON FULL SCALE AIRCRAFT

AIRFOIL ILLUSTRATING FEEDBACK CONTROL SYSTEM USING PIEZOELECTRIC ACTUATOR



- Gain Amplified Wing Root Strain Fed Back
- Applied Voltage to Piezoelectric Material Deforms Wing
- Deformed Wing Improves Static Aeroelastic Response

$$\text{Wing Loading} = \frac{\text{Aircraft Weight}}{\text{Load Carrying Surface Area}}$$

Wing Loading Increases when:
Changing from Model Scale to Full Scale
Increasing Weight of Full-Scale Aircraft

WING LOADING AND PIEZOELECTRIC EFFECTIVENESS RELATIONSHIP FOR AN UNSWEPT WING

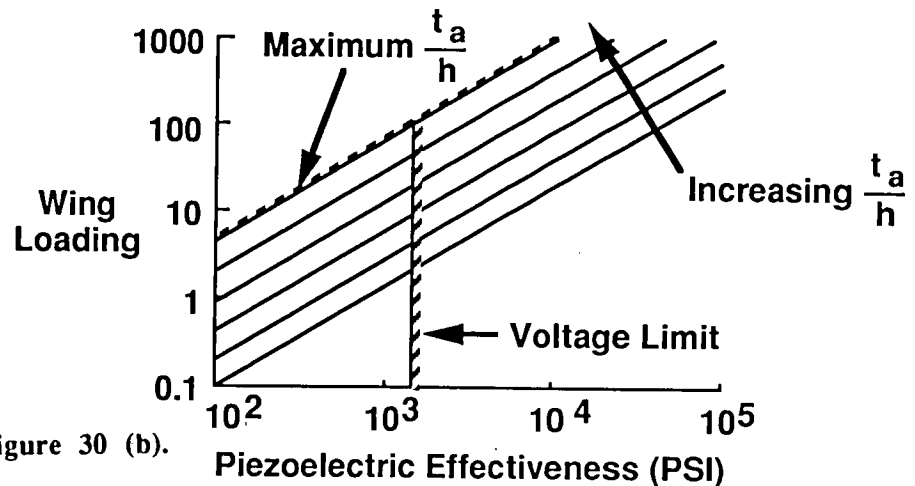


Figure 30 (b).

Piezoelectric Effectiveness (PSI)

WING LOADS ACTIVELY CONTROLLED DURING ROLLING MANEUVERS

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Aeroservoelasticity Branch

Anthony S. Pototzky
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RTOP 505-63-50

Research Objective: The research objective was to develop an active control law concept which will reduce incremental wing loads generated on the Active Flexible Wing (AFW) aeroelastic wind-tunnel model during rolling maneuvers.

Approach: The AFW model is shown in various roll positions at the upper left of the figure. The Rolling Maneuver Load Alleviation (RMLA) control law was designed to alleviate incremental loads generated during rolling maneuvers by using roll rate feedback to actuate one pair of trailing-edge control surfaces and one pair of leading-edge control surfaces. In addition, the control law was constrained to produce control surface deflections and rates which were moderate and analytically did not saturate. The associated closed-loop system gains were determined by classical controls design methodology and optimization to achieve a specified roll performance. The control surface pairs, roll rate gyro, and position of strain gauges used to measure loads are shown schematically at the upper right of the figure.

Accomplishment Description: Baseline incremental loads were obtained from controlled roll maneuvers in which no reduction of the incremental loads was attempted. Peak torsion and bending moment incremental loads obtained during the RMLA-controlled roll maneuvers were compared to baseline incremental loads to determine the RMLA effectiveness. A comparison of the incremental inboard torsional moments, shown at the bottom right of the figure, shows that the RMLA control law reduced the incremental loads by up to 60 percent. The plot of model roll angle versus time with and without the RMLA control law activated, at the bottom left of the figure, shows that the RMLA control law did not affect aircraft performance.

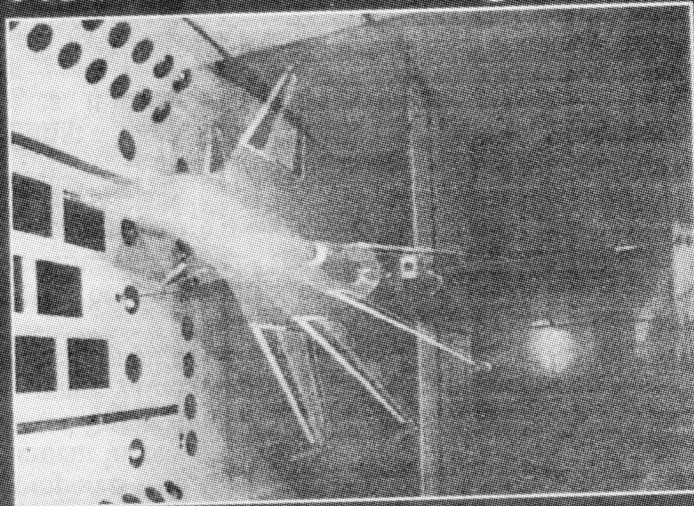
Significance: The demonstrated methodology provides a means by which aircraft wing loads may be alleviated during roll maneuvers. The load alleviation is possible due to the ability of outboard control surfaces to deform the wing and oppose increases in incremental loads. It is possible that this methodology may be applied to other types of aircraft maneuvers.

Future Plans: A paper has been proposed for presentation at the 1992 AIAA Dynamics Specialist Conference.

Figure 31 (a).

WING LOADS ACTIVELY CONTROLLED DURING ROLLING MANEUVERS

Active flexible wing model



Control concept

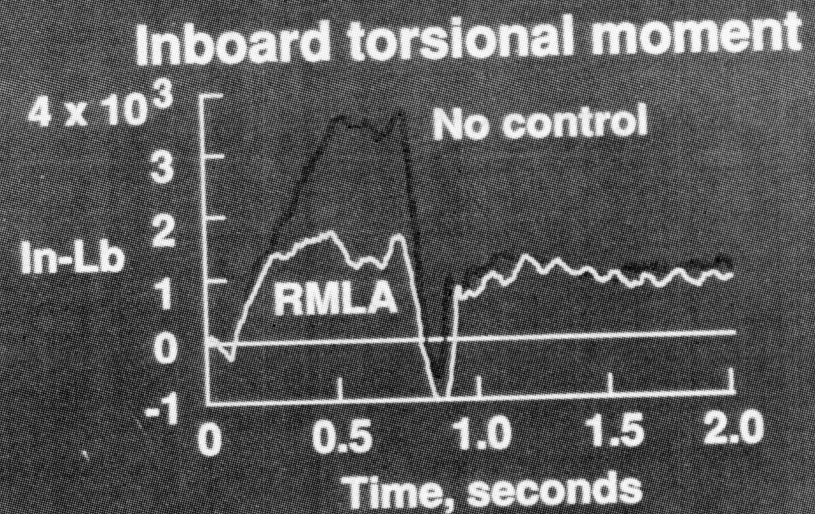
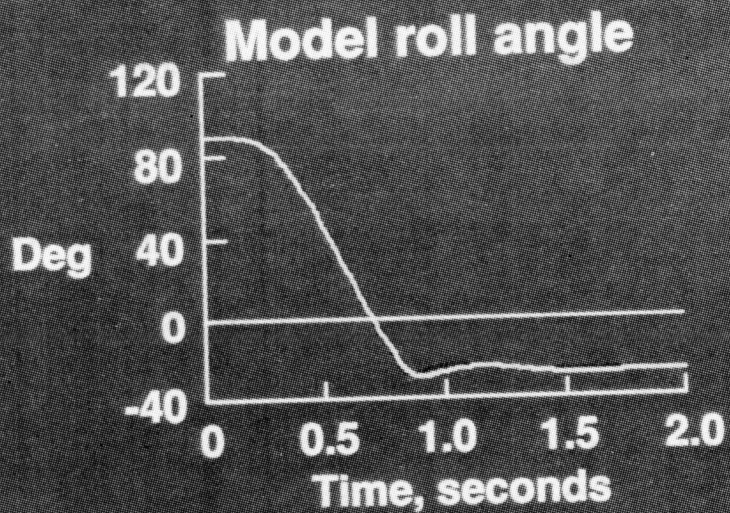
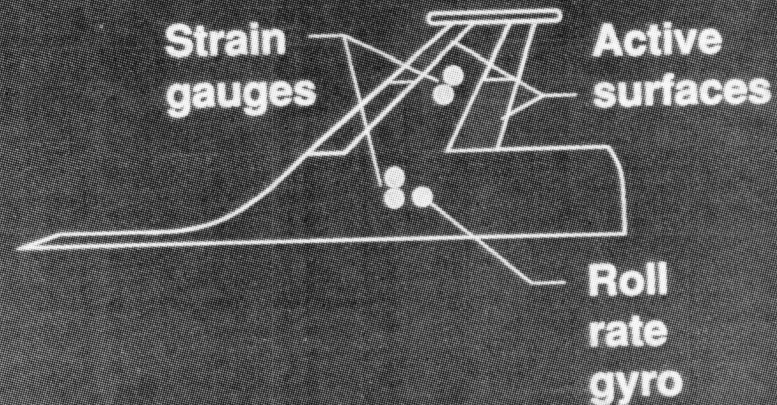


Figure 31 (b).

MULTIPLE FLUTTER MODES SUPPRESSED USING REDUCED ORDER LQG CONTROL LAW IN AFW WIND-TUNNEL TEST

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RTOP 505-63-50

Research Objective: The objective was to design and test digital control laws for the Active Flexible Wing (AFW) aeroelastic wind-tunnel model to suppress its symmetric and the antisymmetric flutter modes simultaneously when the model is not free to roll.

Approach: A fifth-order single-input single-output control law was designed to increase the symmetric and antisymmetric flutter dynamic pressures. The control law used a pair of wing-tip accelerometer sensors and the trailing edge outboard pair of control surfaces shown in the upper left of the figure and was derived using modified Linear Quadratic Gaussian (LQG) theory, order reduction, root-locus study and previous experimental results. First, a full order LQG control law was designed using the antisymmetric state-space model at a dynamic pressure of 350 pounds per square foot (psf). The control law then was reduced in order by residualization, balanced realization and, finally, by truncation and gain augmentation.

6
0 **Accomplishment Description:** Multiple capabilities of the flutter suppression system were demonstrated during wind tunnel tests and compared with the theoretical results. The symmetric and antisymmetric flutter dynamic pressures were increased to 270 psf, a 23-percent increase above the open-loop antisymmetric flutter dynamic pressure of 219 psf. The symmetric, antisymmetric, and augmented flutter dynamic pressures are shown on the constant enthalpy line plotted at the right of the figure. The maximum root-mean-square values of the control surface deflections and rates are shown at the lower left. These deflections and rates were well within the capabilities of the hydraulic actuators.

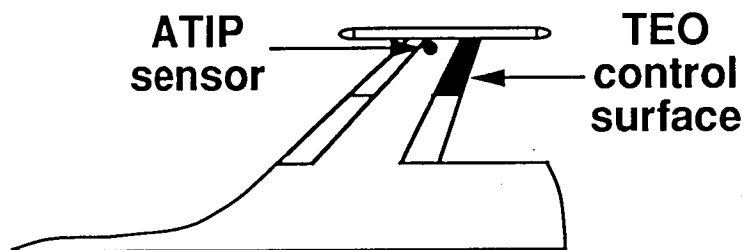
Significance: The same control law was used to augment the symmetric and antisymmetric flutter boundaries and theoretically was shown to stabilize a variety of state-space models with flutter frequencies ranging from 9 Hz to 13 Hz at a dynamic pressure of 250 psf. The experimental frequency responses, singular values, gain and phase margins were in good qualitative agreement with the theoretical values.

Future Plans: The experimental data will be used for better modeling of the system and improve control law design methodologies. It is planned to present these results at the 1992 AIAA Dynamics Specialists Conference.

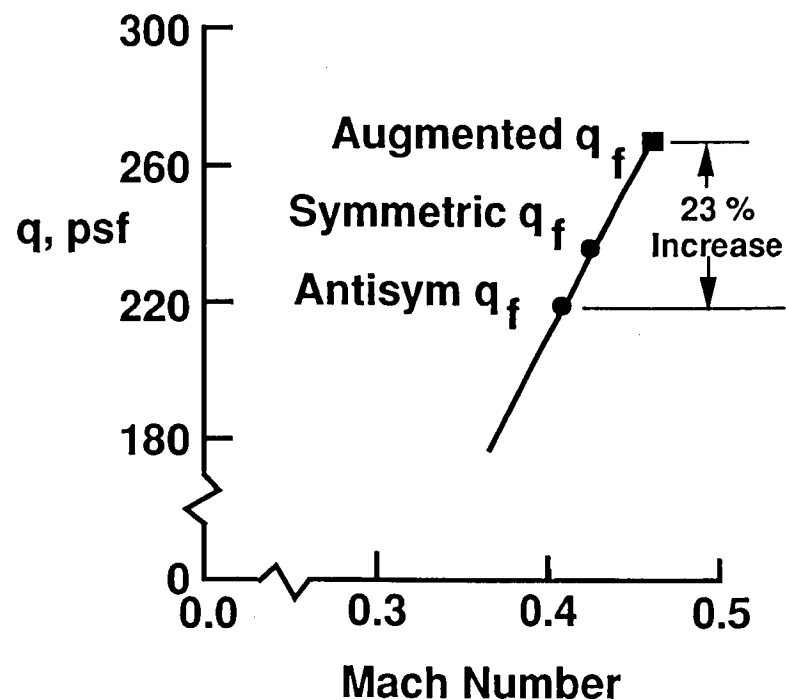
Figure 32 (a).

MULTIPLE FLUTTER MODES SUPPRESSED USING REDUCED ORDER LQG CONTROL LAW IN AFW WIND-TUNNEL TEST

Sensor and Control Surface



Multiple Flutter Dynamic Pressure Augmentation



Control Surface Activity Demands

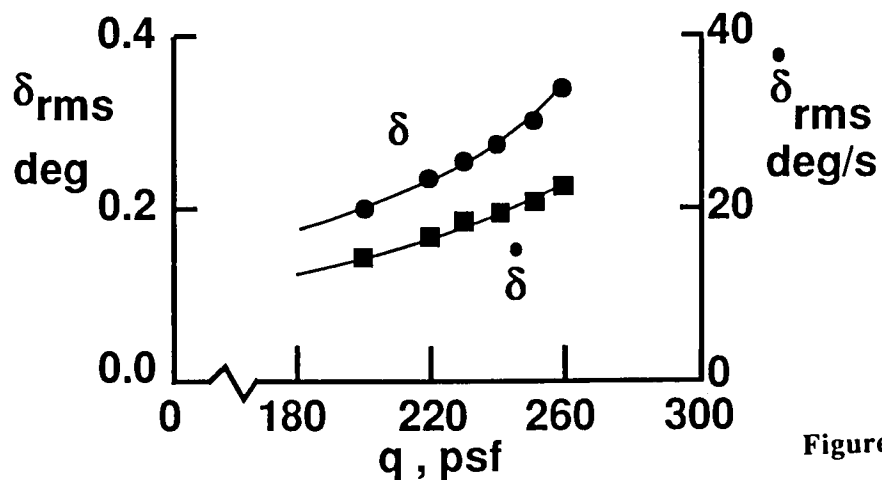


Figure 32(b).

FLUTTER SUPPRESSION USING PIEZOELECTRIC ACTUATION DEMONSTRATED IN THE WIND TUNNEL

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RTOP 505-63-50

Objective: There has been considerable research in developing flutter suppression system (FSS) concepts which use conventional aerodynamic control surfaces. The catastrophic nature of flutter, however, requires that the issues of flight safety (system redundancy, reliability, and maintainability) be addressed before an FSS can become a common practice in today's aerospace industry. To a lesser extent, the control surface authority available to maneuver an aircraft with the simultaneous implementation of an FSS also needs further investigation. To alleviate these concerns alternative FSS concepts are being studied. Secondary controllers which consist of locally-attached plates made of adaptive material capable of inducing forces and moments on a structure is one such concept. The objectives of this research were to: 1) assess the state-of-the-art for modeling adaptive material characteristics; 2) analytically establish the feasibility of using adaptive material plate actuators to suppress flutter; and 3) conduct wind-tunnel tests to provide data for validating the predictions.

92 **Approach:** A two-degree of freedom wind-tunnel mount system was designed and fabricated to cause the rigid wing shown in the photo to flutter within the wind-tunnel operating envelope. Actuators made of piezoelectric material, a subcategory of adaptive material, were affixed to the bending leaf springs of the mount system. A mathematical aeroservoelastic model was constructed using finite element methods, laminated plate theory, and aeroelastic analysis tools. Plant characteristics were determined from this model and verified by open-loop tests. From this information, an FSS control law was designed and digitally implemented. Theoretically, command signals from the FSS controller applied to the piezoelectric actuators were shown to exert control over the damping and stiffness properties of the bending degree of freedom, thus delaying flutter onset. Closed-loop flutter testing was conducted to verify those conclusions.

Accomplishment Description: Analysis of the open-loop aeroelastic equations of motion produced a flutter condition at 560 inches per second (ips) at a frequency of 9.1 Hz; experimentally, the flutter speed was measured at 580 ips at 9.4 Hz. A gain feedback control law was designed utilizing the intrinsic dynamics of the digital computer to simulate derivative feedback of strain. Only one actuator, consisting of two plates measuring 1.5 by 1 inches and .0075 inches thick, was used. The analytical closed-loop flutter prediction was 648 ips; experimentally, flutter occurred at 697 ips, a 20% increase in flutter speed.

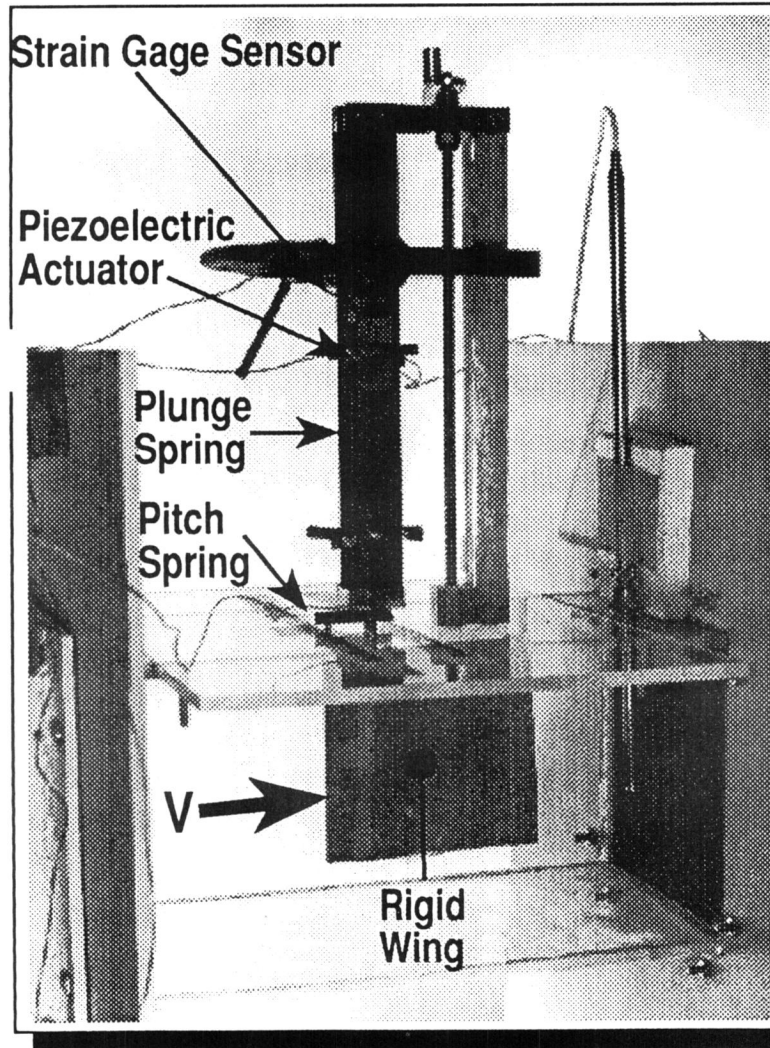
Significance: The experimental results represent the first demonstration of using adaptive materials to actively suppress flutter. It demonstrates that carefully placed small actuating plates can be used effectively to control aeroelastic response of flight vehicles.

Future Plans: The results of this study will be presented in April 1992 in Dallas at the AIAA Structures, Structural Dynamics, and Materials Conference. In addition, a cooperative wind-tunnel program with MIT will further investigate the use of adaptive materials for alleviating aeroelastic response. The integration of adaptive materials with classical aerodynamic control concepts will also be addressed.

Figure 33 (a).

FLUTTER SUPPRESSION USING PIEZOELECTRIC ACTUATION DEMONSTRATED IN THE WIND TUNNEL

2 Degree-of-Freedom Wind Tunnel Model



- Open Loop Analysis
- Open Loop Experiment
- * Closed Loop Analysis
- Closed Loop Experiment

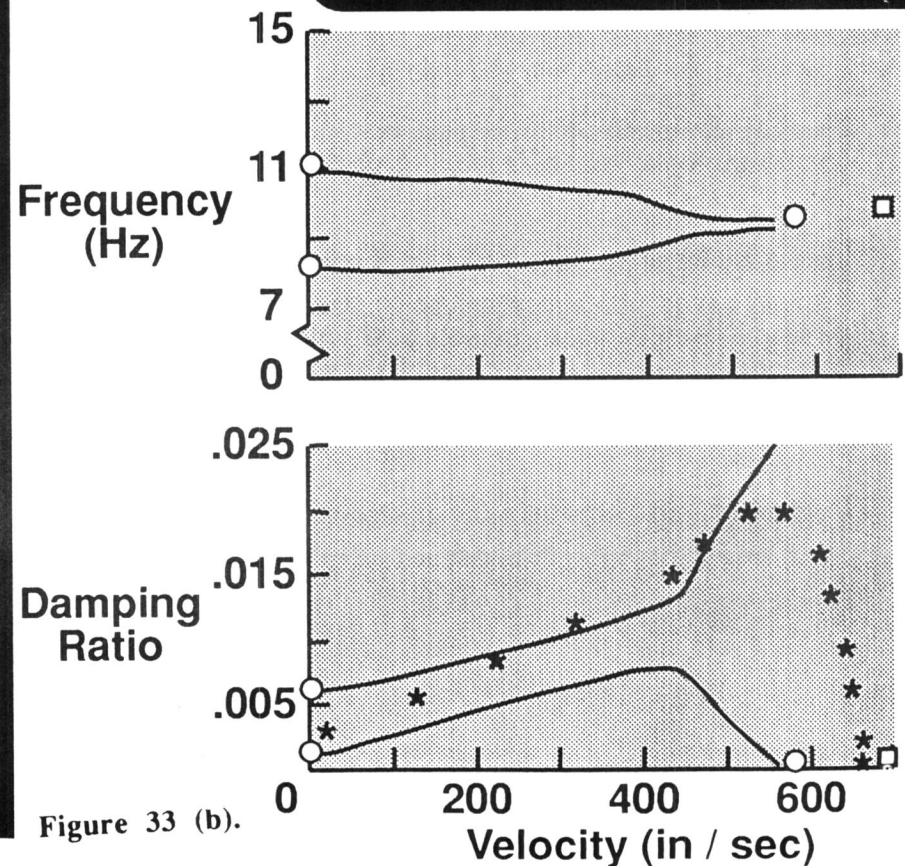


Figure 33 (b).

ADVANCED CONTROL LAW DESIGNS USED TO SUCCESSFULLY DAMP STRUCTURAL RESPONSE

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RTOP 505-63-50

Research Objective: The objective of this study is to develop the methodology and procedures for applying LQR/LQG, H_∞ , and μ -synthesis techniques in the design of control laws for alleviating structural vibrations associated with large structures or undesirable aeroelastic response of flexible flight vehicles.

Approach: Vibration suppression control laws were designed using H_∞ , μ -synthesis and LQR/LQG techniques. Each of the control laws were implemented on an Intel 80386 microcomputer that used the Lynx Real-Time Operating System. To examine the capability of each of these different control law designs, the 10-bay truss beam shown in the figure was perturbed with an impulse. Tip accelerations were sensed and compensated by the controller to command the thrusters located at the end of the beam. Experimental and analytical results based on the H_∞ and μ -synthesis techniques were compared with results obtained using the more conventional LQR/LQG control law design procedures.

94 **Accomplishment Description:** An experimental system identification procedure was used to identify a simple fourth-order system (2 modes) associated with the bending modes of the beam. This fourth-order system was used as the design model for the control law design algorithms. The accompanying figure shows a sampling of the results of the investigation. The damping of the in-plane bending mode predicted by analyses and measured during the experiment with the H_∞ control law operating is shown plotted versus a control law design variable ρ . In addition, the behavior of a compensator root predicted by analysis is also plotted. During the experiment only the lowest damp root was measured. The agreement between the analysis and test is excellent, particularly at the larger values of ρ .

Significance: The design, analysis, and testing of control laws based on LQR/LQG, H_∞ , and μ -synthesis methodologies have contributed significantly to the basic understanding and limitations of these advanced, robust design techniques. Also, this project was the first to use a real-time Unix Operating System for the control of the dynamic response of a flexible structure.

Future Plans: Plans are to continue investigating the use of LQR/LQG, H_∞ , and μ -synthesis control law design methodologies for application to flexible aircraft to alleviate undesirable aeroelastic response.

Figure 34 (a).

ADVANCED CONTROL LAW DESIGNS USED TO SUCCESSFULLY DAMP STRUCTURAL RESPONSE

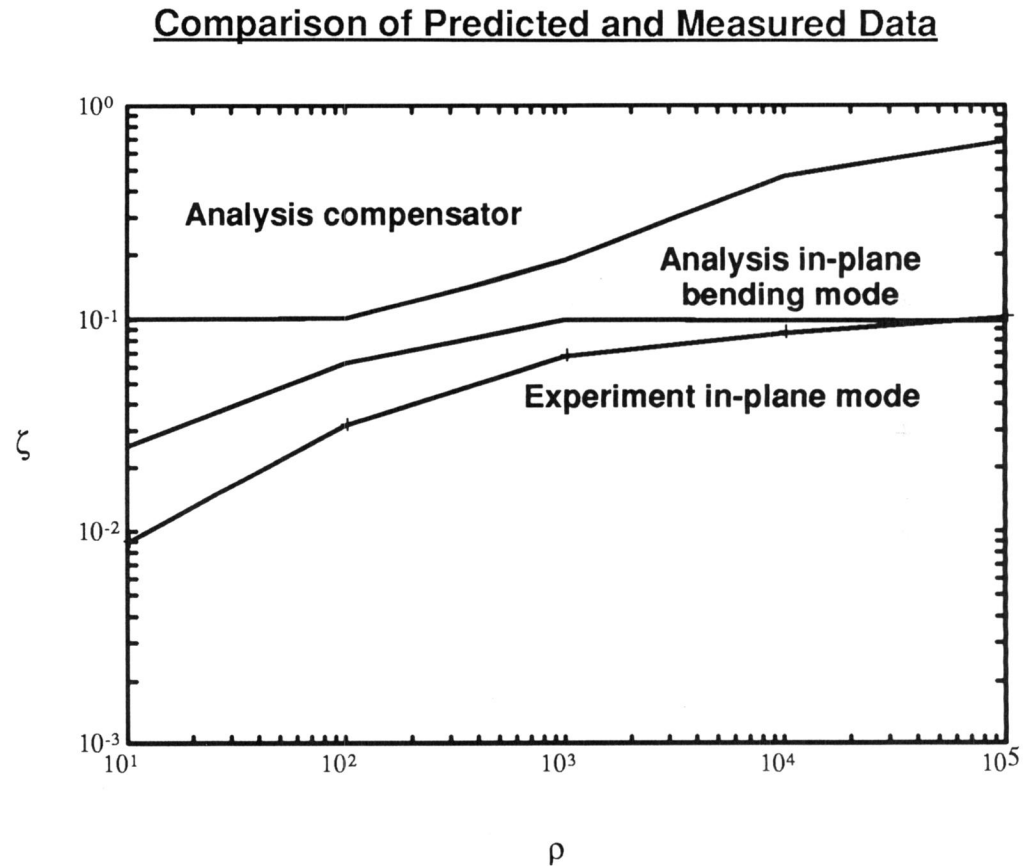
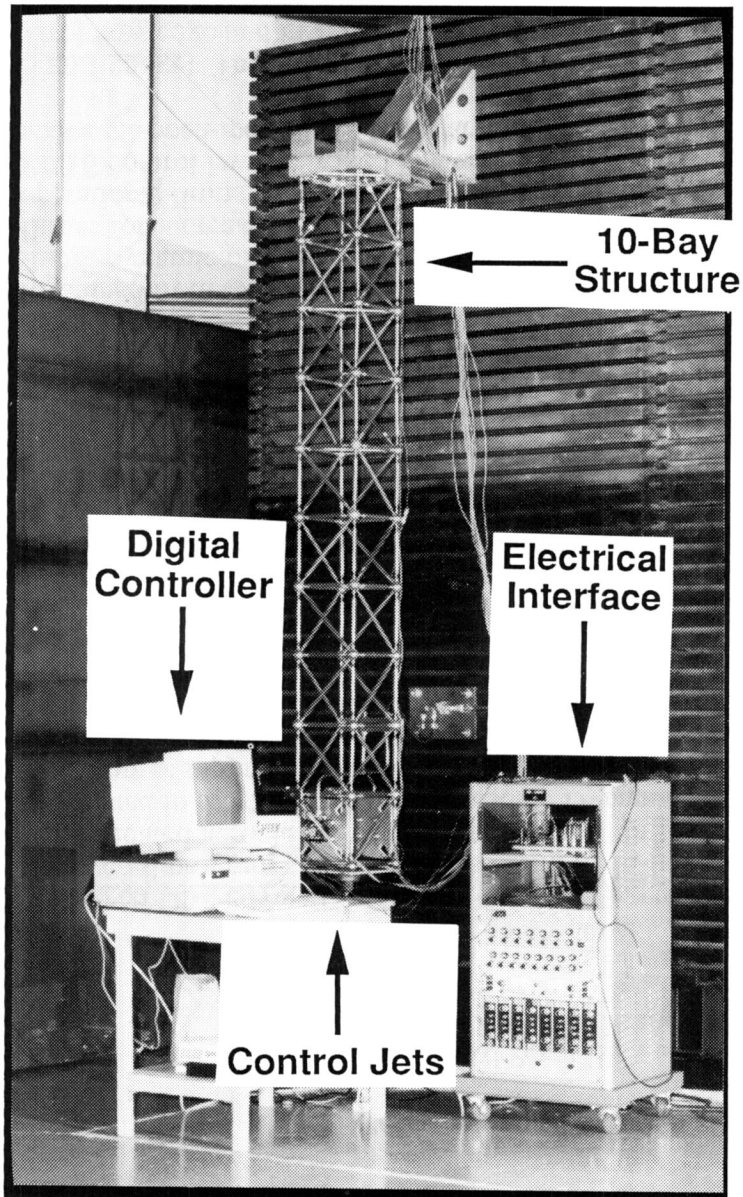


Figure 34 (b).

COOPERATIVE AFW PROGRAM SUCCESSFULLY COMPLETED

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Stanley R. Cole
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RTOP 505-63-50

Research Objective: The Active Flexible Wing (AFW) Program is a cooperative NASA-LaRC/Rockwell International effort with the overall program goal of demonstrating multi-input/multi-output (MIMO) single-function and multi-function digital control of a sophisticated aeroelastic wind-tunnel model. In the Winter of 1991 the second of two tests of the AFW wind-tunnel model was conducted in the NASA LaRC Transonic Dynamics Tunnel. The single-function MIMO digital control capabilities demonstrated were flutter suppression systems (FSS), a roll rate tracking system (RRTS), and rolling maneuver load alleviation (RMLA). The multi-function MIMO digital control involved flutter suppression in conjunction with one of the rolling control laws. The research objective of the program is to validate analysis, synthesis, simulation, and test methodologies necessary to perform such demonstrations.

Approach: The approach taken to accomplish the research objective was to design, implement, and test single-function and multi-function MIMO control concepts on the AFW wind-tunnel model. The AFW model, shown in the figure, had the capability of rolling on the sting support. This feature of the model allowed for the rolling maneuver load demonstrations to be conducted.

96 **Accomplishment Description:** The accomplishments can be categorized as technology developments and as wind-tunnel test demonstrations. The most significant accomplishments in each category are listed in the accompanying figure. Under technology developments: a real-time multi-function digital controller was designed, assembled, coded, validated, and tested; a near-real-time simulation of the aeroservoelastic equations of motion was implemented and used to validate the functionality of the AFW digital controller before each wind-tunnel test; and a wing-tip flutter stopper (based on the decoupler pylon principle) was conceived, designed, fabricated, installed, and tested on the model. Under wind-tunnel test demonstrations: in one model configuration (model restrained from rolling) two flutter modes were suppressed simultaneously by each of three FSS control laws resulting in increases in flutter dynamic pressures of 20 - 25 percent; in another model configuration (model free to roll) four FSS control laws suppressed flutter for increases in flutter dynamic pressures of at least 26 percent (further increases were not possible because wind-tunnel operational limits were encountered); an RMLA control law reduced key wing loads by 60 percent during rapid roll maneuvers; an RRTS control law controlled key wing loads during Mil Spec roll maneuvers; and multi-function MIMO control was demonstrated above the open-loop flutter boundary.

Significance: The AFW program has afforded the opportunity to validate analysis, synthesis, simulation, and test methodologies. The knowledge and insight gained from the AFW program, especially where experimental results and analytical predictions differ, are extremely valuable and may be applied to future projects.

Future Plans: Two sessions at the AIAA 1992 Dynamic Specialists Conference will be devoted to the AFW program.

Figure 35 (a).

COOPERATIVE AFW PROGRAM SUCCESSFULLY COMPLETED

Technology Developments

- Real-time, multi-function digital controller
- Near real-time aeroservoelastic simulation
- Wing-tip flutter stopper: concept thru hardware

Wind Tunnel Test Demonstrations

- Single - and multiple - mode flutter suppression up to tunnel limit
- Significant load reduction during rapid roll maneuvers
- Load control during mil-spec roll maneuvers
- Multi-function active controls above flutter boundary

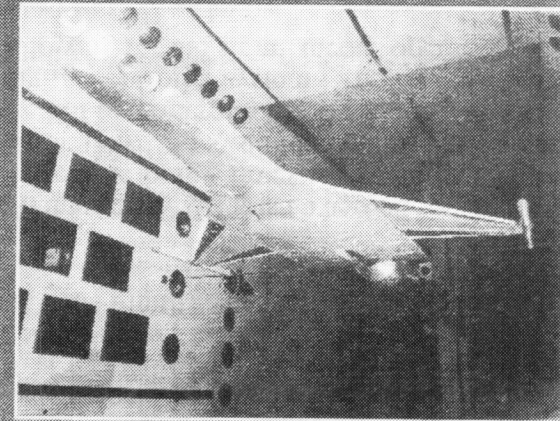


Figure 35 (b).

MULTI-INPUT/MULTI-OUTPUT DIGITAL CONTROLLER ALLOWS MULTIFUNCTION ACTIVE CONTROL OF AEROELASTIC RESPONSE

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Aeroservoelasticity Branch

Sandra M. McGraw
Lockheed Engineering and Sciences Co.

RTOP 505-63-50

Research Objective: The Active Flexible Wing (AFW) Program is a cooperative effort between the NASA Langley Research Center and Rockwell International Corporation. Among the program objectives is the validation of analysis and synthesis methodologies as applied to the multifunction control of a sophisticated aeroelastic wind-tunnel model. The research objectives include gaining practical experience in designing, fabricating, and implementing a real-time multifunction multi-input/multi-output (MIMO) digital controller system and its hardware/software interfaces.

Approach: The AFW wind-tunnel model was tested during the Fall of 1989 and the Winter of 1991. It is an aeroelastically-scaled, full-span, free-to-roll model of an advanced fighter configuration. The control functions being investigated included flutter suppression systems (FSS), a roll trim system (RTS), a rolling maneuver load alleviation (RMLA) system, and a roll rate tracking system (RRTS). The basic approach was to design a digital controller system comprised of two microprocessors, each performing a specified control function. A third processor performed timing control of the entire digital controller system. The digital controller system operated at 200 Hz within a much slower host operating system environment allowing for the simultaneous operation of FSS and either RTS, RMLA, or RRTS.

Accomplishment Description: An extremely versatile real-time multifunction digital controller system, shown schematically at the left of the figure, has been developed for the AFW program. The system operates independently of the operating system of the host computer, at speeds up to four times faster than the host environment normally permits. It allows for simultaneous execution of different control laws which are implemented in a variety of ways. It synchronizes the operation of four processing units, allows flexibility in the number, form, functionality, and order of implemented control laws and variability in selection of sensors and actuators employed. It coordinates the acquisition, storage, and transfer of data for near real-time controller performance evaluation and open- and closed-loop plant estimation. Most importantly, the digital controller system allowed the successful demonstration of control laws which were designed using classical and modern synthesis methods and implemented various ways.

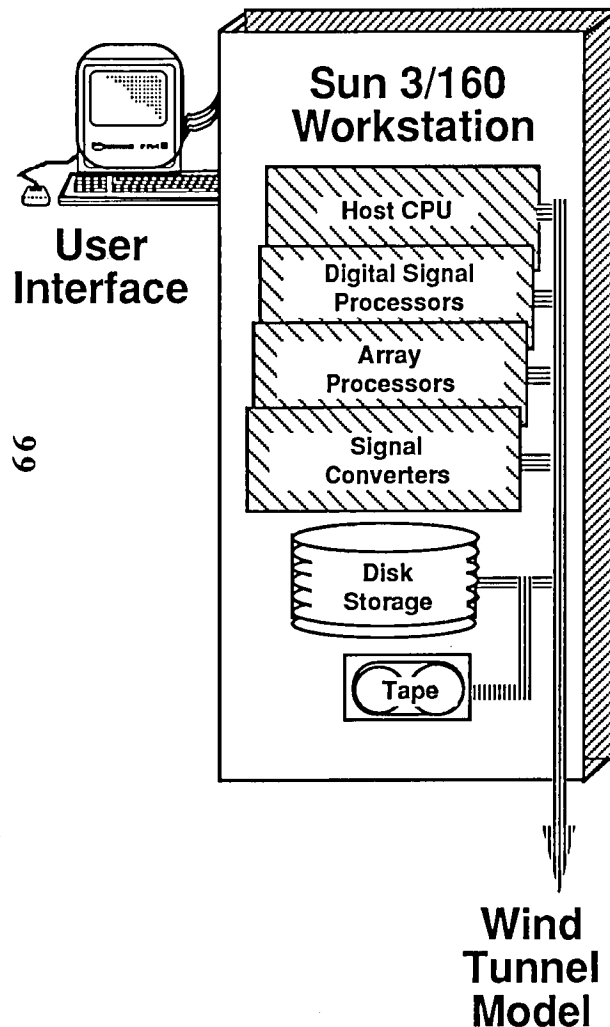
Significance: The digital controller developed for this program was the central element of a four-calendar-year, 25-person-year effort, providing the crucial link between control law design and implementation and between concept and reality.

Future Plans: The digital controller system is the subject of two proposed conference papers (1992 AIAA Dynamic Specialists Conference, 1992 CSI Conference) and of proposed NASA formal reports. The digital controller system will be modified as necessary to support the NASA LaRC Benchmark Models Program.

Figure 36 (a).

MULTI-INPUT/MULTI-OUTPUT DIGITAL CONTROLLER ALLOWS MULTIFUNCTION ACTIVE CONTROL OF AEROELASTIC RESPONSE

Features/Capabilities



- 200 Hz Sampling Rate
 - Can control structural frequencies up to 35Hz
- Single Function Controllers
 - Flutter Suppression System (FSS)
 - Roll Trim System (RTS)
 - Rolling Maneuver Load Alleviation (RMLA)
 - Roll Rate Tracking System (RRTS)
- Multifunction Controllers
 - FSS/RTS
 - FSS/RMLA
 - FSS/RRTS
- Data Acquisition for On-Line Analysis of Stability and Performance
- Rapid Control Law Implementation
- Versatile, User Friendly

Figure 36 (b).

OPEN LOOP FLUTTER CHARACTERISTICS DETERMINED FROM CLOSED LOOP DATA

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Lockheed Engineering and Sciences Corporation

Carol D. Wieseman, Sherwood T. Hoadley and Vivek Mukhopadhyay
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The objective of this activity is to develop the tools for determining, under near real-time conditions, the open-loop flutter dynamic pressure and frequency while conducting closed-loop flutter suppression (FS) wind-tunnel testing.

Approach: A near real-time methodology was developed that is applicable to multivariable control systems and implementable on microcomputers. The methodology requires the systematic excitation of the wind-tunnel model by the FS control surfaces at various test conditions. From these recorded excitations and the associated time responses of specific sensors on the wind-tunnel model (plant) and at the controller output, the closed-loop transfer matrices in the frequency domain can be digitally computed using signal processing techniques. A matrix procedure is used to determine the open-loop transfer matrices of both the plant and the controller from the closed-loop matrices. The inverse of the maximum singular values of the extracted open-loop plant transfer matrix is used as an indicator of poles in the proximity of the imaginary axis of a root locus plot.

Accomplishment Description: The accompanying figure provides some of the results of applying this methodology during the Active Flexible Wing wind-tunnel tests. The plot on the left provides a curve of the inverse of the maximum singular values obtained using the procedures described above versus frequency for a specified dynamic pressure. The proximity of the inverse of the maximum singular value to zero (shown by an arrow) is an indication of how close the model is to open-loop flutter or neutral stability. The minimums at different dynamic pressures are then plotted as a function of dynamic pressure, shown in the top right figure. A curve through the experimental data provides an estimate of the flutter dynamic pressure. The flutter condition is denoted by the dashed line emanating from the upper right plot. An estimate of the flutter frequency is provided on the lower right plot. The flutter dynamic pressure of 235 psf and the flutter frequency of 9.8 Hertz of the open-loop plant obtained during closed-loop testing nearly matched the measurements obtained by other methods during open-loop flutter testing as shown in the table at lower left.

Significance: This method gives a means of assessing the stability of the open-loop plant under closed-loop conditions and is especially valuable under conditions where the plant is open-loop unstable. During wind-tunnel testing, this methodology provided a near real-time procedure for alerting the test engineer of a potentially destabilizing condition.

Future Plans: The method will be used during closed-loop flutter suppression testing of the active controls model of the Benchmark Models Program.

Figure 37 (a).

OPEN-LOOP FLUTTER CHARACTERISTIC DETERMINED FROM CLOSED-LOOP DATA

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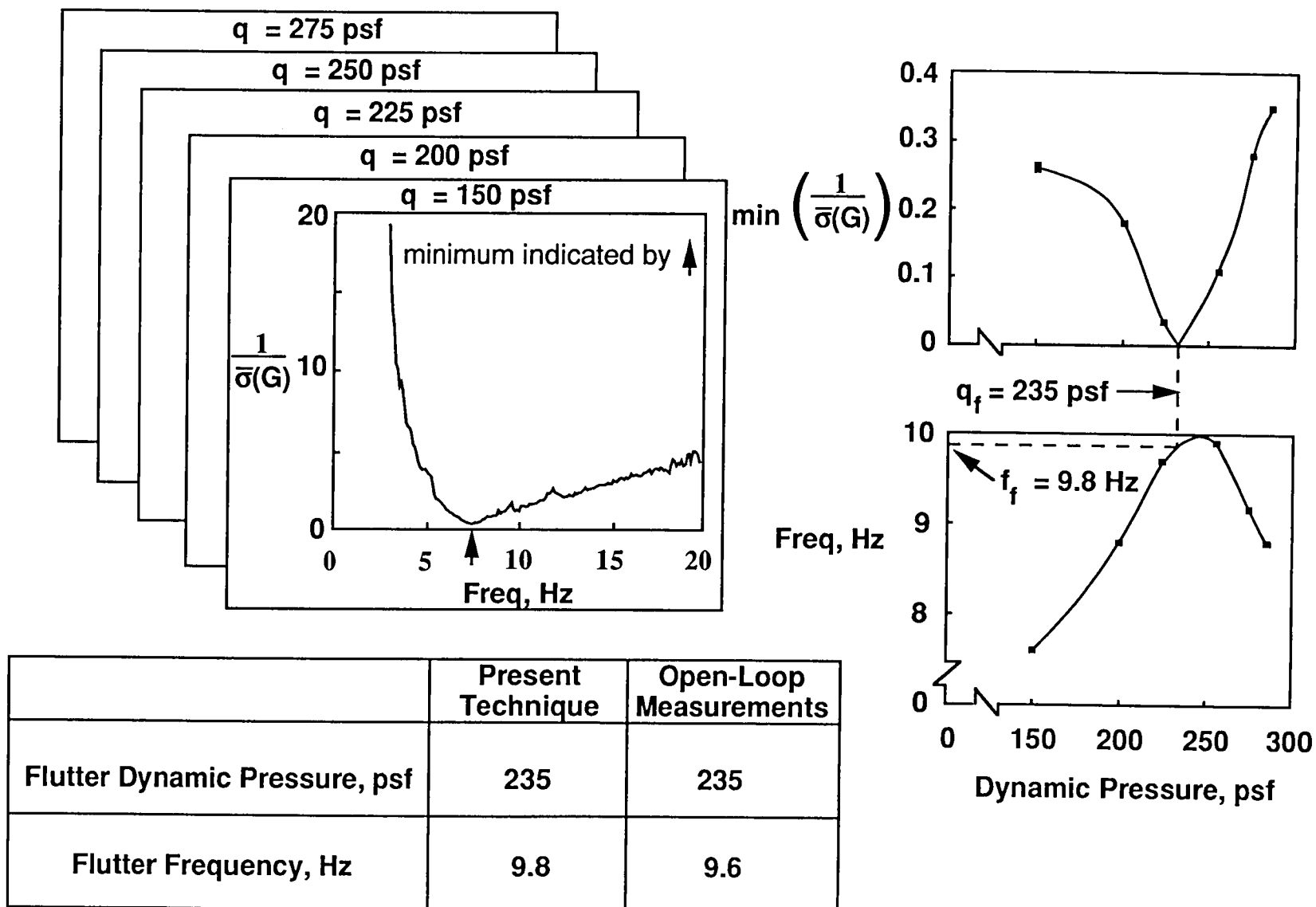


Figure 37 (b).

FLUTTER CHARACTERISTICS OF GENERIC HYPERSONIC VEHICLE ANALYZED WITH AEROELASTIC VEHICLE ANALYSIS (AVA) CODES

Thomas A. Zeiler and Anthony S. Pototzky
Lockheed Engineering and Science Corporation

RTOP 505-63-50

Objective: The objective of the present work is to perform flutter analyses on a generic hypersonic vehicle (top figure) at subsonic and supersonic, unheated conditions.

Approach: Modal characteristics obtained from a finite element model were used in the Aeroelastic Vehicle Analysis (AVA) system of codes, developed within ASEB, to analyze the generic hypersonic vehicle for flutter at Mach numbers M of 0.5 and 4.0. The aerodynamic representation of the vehicle was as a set of flat plate lifting surfaces with the wing, body, and vertical tail modeled. Structural damping of three percent was added to the elastic modes, and rigid-body plunge and pitch were included in the analysis.

Accomplishment Description: The vehicle's wing is attached to the fuselage by an all-moveable pivot, with torsional stiffness in the pivot providing restraint when the wing is locked into position. The first elastic mode of the vehicle is dominated by torsional flexing at the pivot, resulting in angle-of-attack motion of the wing. Subsonically, this mode washes in, accentuating the torsional deformation and lowering the effective stiffness of the mode. This same wash-in serves to increase the effective stiffness of the vehicle short period mode. The result (left root locus plot) is that the short period and first elastic modes encounter frequency coalescence, and a body-freedom flutter condition occurs at an airspeed of 847 knots equivalent airspeed (keas). The other elastic modes are affected very slightly. At $M = 4.0$, however, the center of pressure of the wing is further aft, resulting in an aeroelastic wash-out of the wing. This has the opposite effect on the short period and wing pivot modes and, thus, they do not coalesce. Instead, elastic modes 1 and 2 (dominated by body bending with some pivot torsion) coalesce with flutter occurring at 948 keas in a lightly damped "hump" mode (right root locus plot). Mode 2 stabilizes at 1283 keas, but mode 1 flutters shortly thereafter at 1308 keas in a much more violent mode of instability, possibly as a result of further coalescence with elastic mode 2 or with elastic mode 4 (dominated by wing bending and pivot torsion).

Significance: The results of this analysis showed at least three modes of flutter instability that could occur. The type of flutter depends upon whether the Mach number is subsonic or supersonic. For the subsonic analyses a low frequency body freedom flutter instability was predicted; at supersonic conditions a lightly damped "hump" mode of instability was predicted, but after the mode restablizes at higher speeds a more violent mode instability was predicted to occur.

Future Plans: The effects of aerodynamic heating of the vehicle structure on these flutter characteristics will be studied for several Mach numbers selected from a representative flight trajectory.

Figure 38 (a).

Flutter Characteristics of Generic Hypersonic Vehicle Analyzed With Aeroelastic Vehicle Analysis (AVA) Codes

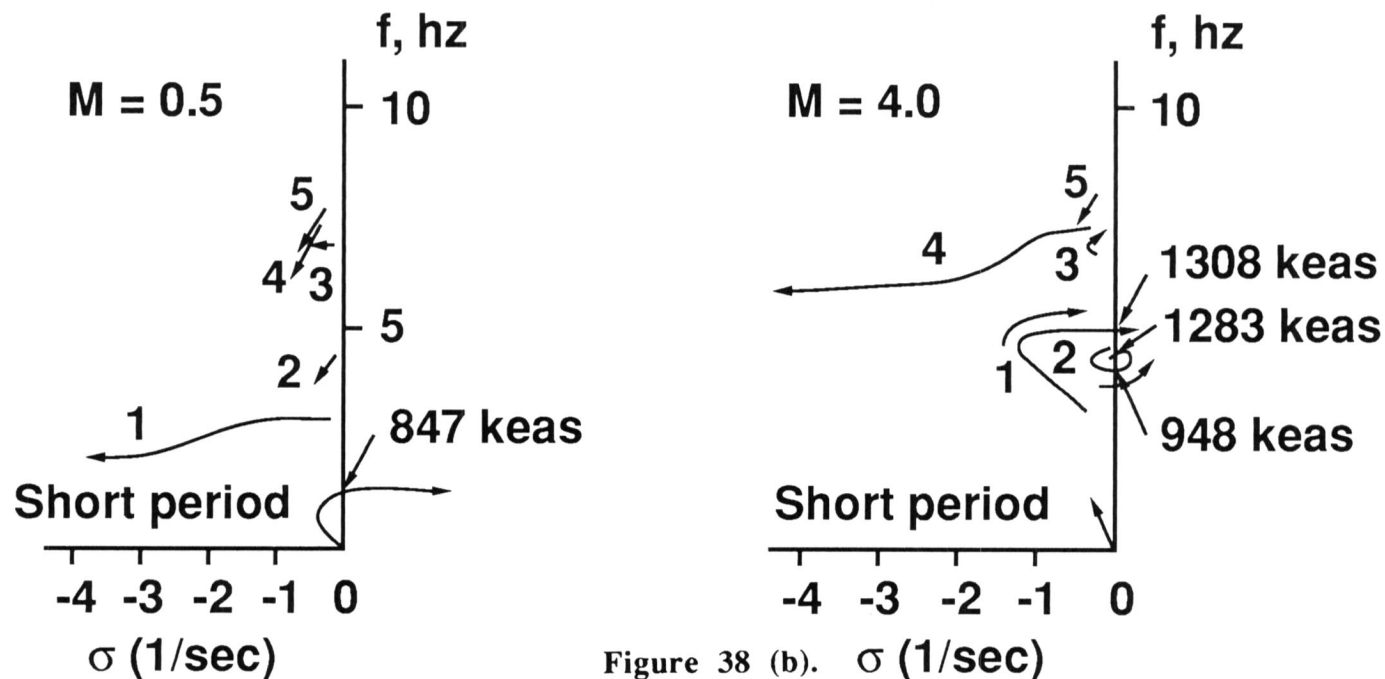
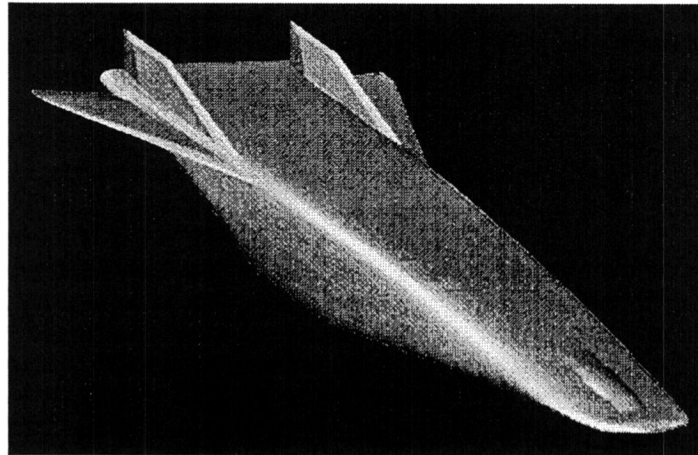


Figure 38 (b). σ (1/sec)

SURFACE HEATING CHARACTERISTICS OF A GENERIC HYPERSONIC VEHICLE PREDICTED

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Lockheed Engineering and Sciences Corporation

Jennifer Heeg and Woodrow Whitlow, Jr.
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objective: The research objective is to study the effects of aerodynamic heating on the aeroelastic characteristics of a generic hypersonic vehicle configuration and to develop the necessary tools to analyze this type vehicle successfully.

Approach: Aerothermoelastic analysis of the generic hypersonic vehicle configuration involves the following steps: (1) the generation of vehicle surface temperatures at the appropriate flight conditions; (2) the application of the temperatures to change the finite element material properties and to obtain structural stiffness changes caused by thermal stresses; (3) the performance of vibration analyses on the "heated" structure at the various temperature conditions; and (4) the application of the necessary aeroelastic analyses. The Hypersonic Arbitrary Body Program of the Aerodynamic Preliminary Analysis System (APAS) was used to generate radiation wall temperatures on the vehicle at the various flight conditions. Since temperature distributions are generated at the panel locations of APAS, a surface interpolation scheme is used to calculate the temperatures at finite element locations. An element property interpolator outputs applicable structural properties for each element based on interpolated temperatures. With the appropriate thermal expansion coefficients, the structure also is thermally loaded based on the interpolated temperatures to allow the internal stresses to be calculated. The effects of these stresses than are embedded into the stiffness matrix. The thermal prestressing effect causes the largest change in the stiffness matrix. The vibration analyses are conducted using the vehicle stiffness matrix modified by the appropriate thermal conditions and the mass matrix modified according to proper fuel loading conditions. At this point, aeroelastic analyses can be performed on the vehicle.

Accomplishment Description: Surface temperature distributions on the generic hypersonic vehicle at key points of a typical NASP ascent trajectory have been computed using the APAS code. Temperature distributions on the vehicle are shown at the top of the figure. The data at the top left of the figure is for the vehicle traveling at a Mach number M of 5 and depicts relatively cool temperatures. At $M = 15$, the surface temperatures are elevated to their highest values, and at $M = 25$, the vehicle has cooled as a result of flying through a very rarified atmosphere.

Significance: A capability is being developed to perform aeroelastic analyses of a generic hypersonic vehicle through its full flight trajectory. The analysis tools being developed also will be valuable for application to other configurations.

Future Plans: The temperature distributions generated by the APAS code will be used to modify the structure of the hypersonic vehicle for aeroelastic studies. Temperature distributions also will be used as surface boundary condition for Navier-Stokes codes. The APAS code also generated stability derivatives, pressure distributions, and other aerodynamic parameters. These results will be used to benchmark steady aerodynamic results of linear unsteady aerodynamic codes and Navier-Stokes codes over the vehicle's Mach number range.

Figure 39 (a).

Surface Heating Characteristics of a Generic Hypersonic Vehicle Predicted

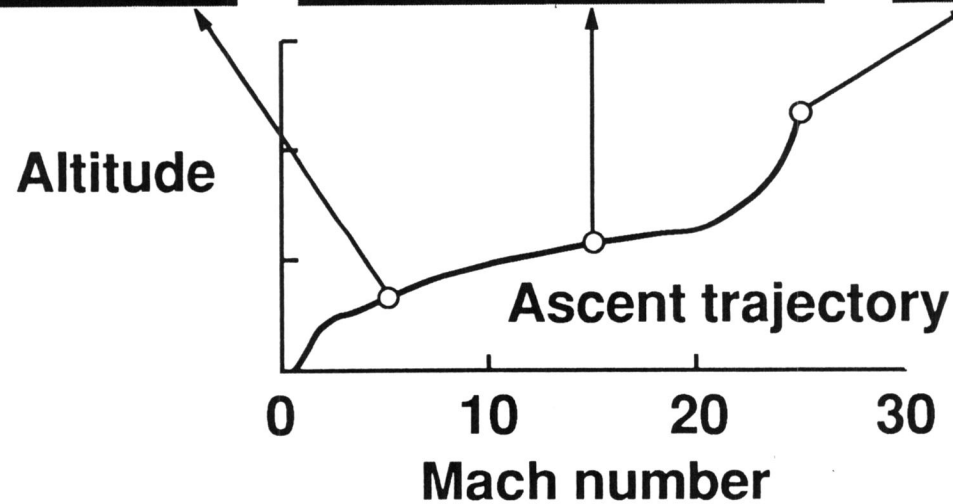
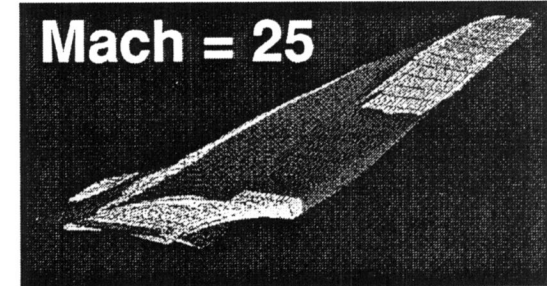
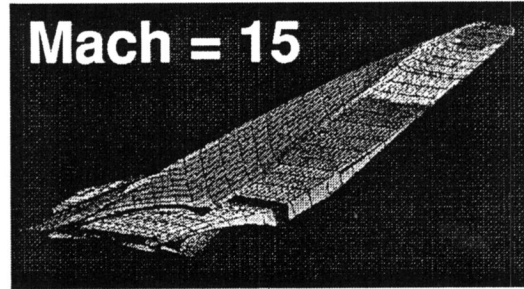
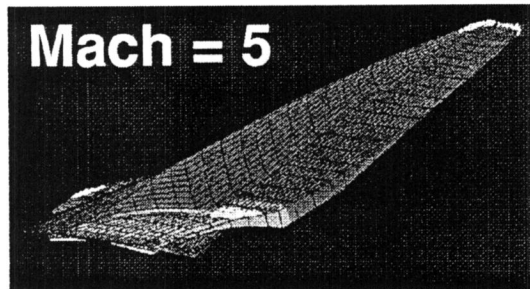
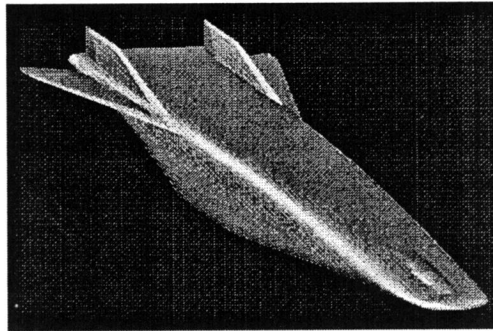


Figure 39 (b).

NONLINEAR AERODYNAMIC LOADS CALCULATED ON GENERIC HYPERSONIC VEHICLE

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Gena M. Humphrey
Florida A & M University

Edward G. Wilson
Old Dominion University

RTOP 505-63-50

Research Objective: The objective of this research is to perform aeroservoelastic (ASE) analyses on a generic hypersonic vehicle in the transonic speed range and to design active flight control systems to alleviate any adverse aeroelastic response.

Approach: Accurate aeroelastic analyses of vehicles flying at transonic speeds requires the computation of nonlinear aerodynamic phenomena such as embedded shock waves. In this approach, inviscid transonic small disturbance (TSD) potential aerodynamics are used. The CAP-TSD code is being used to calculate aerodynamic loads on the generic hypersonic vehicle shown at the center of the figure and to perform aeroelastic analysis. The analysis requires that steady loads be calculated first to determine static deformations, followed by simultaneous integration of the unsteady TSD potential equation and the aeroelastic equations of motion. The results of the aeroelastic analyses provide data necessary to design flight control systems.

Accomplishment Description: Initial steps have been taken to perform aeroelastic analyses of the wing and vertical tail components of the vehicle. A typical cross section of the wing and tail is shown at the upper left of the figure. Steady aerodynamic loads were calculated at Mach numbers M ranging from 0.6 to 0.95. Shown at the lower left of the figure are a pressure distribution along a selected chord of the wing and contours of the lifting pressures for $M = 0.6$ and angle of attack of four degrees. A pressure distribution along a chord of the vertical tail and contours of the surface pressure for $M = 0.6$ and zero incidence angle are shown at the upper right of the figure.

Significance: The results of this effort allow the calculation of the transonic aeroelastic response of a generic hypersonic vehicle and the design of active flight control systems. Current ASE analysis methods use linear aerodynamic methods, and this effort will result in a tool for accurate ASE analyses in the transonic speed range.

Future Plans: After completing ASE analyses using TSD aerodynamics, benchmark analyses using Navier-Stokes methods will be performed to assess the effects of heating on the aeroelastic response of hypersonic vehicles and to design active flight control systems to counteract any adverse effects of the aeroelastic response.

Figure 40 (a).

Nonlinear Aerodynamic Loads Calculated on Generic Hypersonic Vehicle

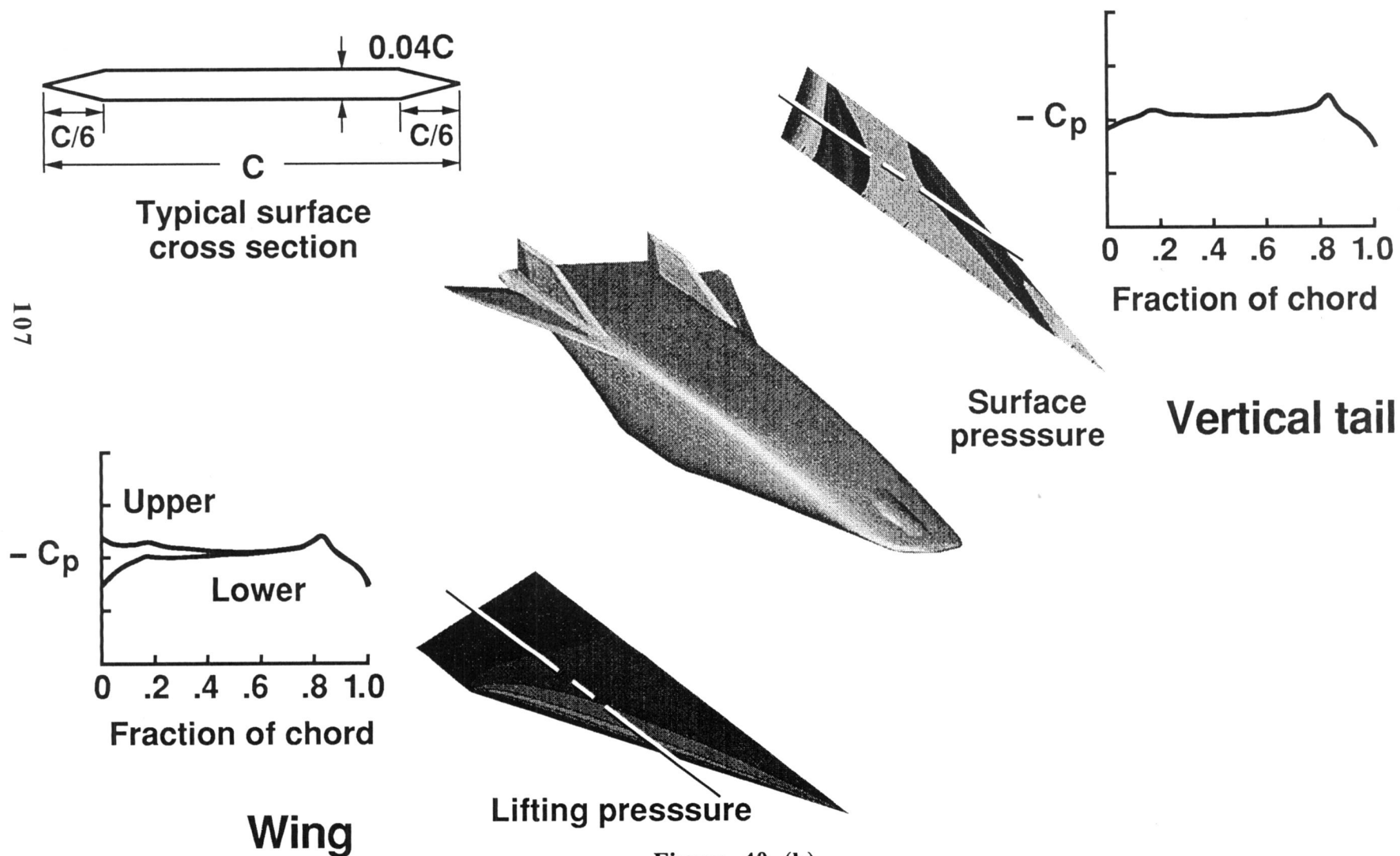


Figure 40 (b).

PARAMETERS FOR IMPROVING TILTROTOR AEROELASTIC STABILITY IN HIGH-SPEED AXIAL FLIGHT IDENTIFIED

Mark W. Nixon
Aeroservoelasticity Branch

RTOP 505-63-36

Research Objective: Recent research efforts have focused on improving tiltrotor aerodynamic performance in both hover and axial flight. Some of these preliminary design efforts have included forward wing sweep while others have employed elastic coupling in a composite rotor blade. Consequently, there is a need for aeroelastic analyses which can accurately predict the stability of these advanced configurations. It is the objective of the present research to develop a comprehensive aeroelastic analysis method capable of modeling generic tiltrotor configurations in all the possible flight modes, and to ascertain, in particular, the influence of wing sweep, thrust level, mode selection, aeroelastic couplings, and aerodynamic modeling on stability.

Approach: The comprehensive tiltrotor analysis method is to be developed in three stages. At each stage there will be an acceptable degree of accuracy such that a particular mode or configuration of the tiltrotor vehicle can be studied. The first stage in the development of the analysis method is confined to axial flight and is based on an elastic swept wing with a rigid rotor. The second stage will have an elastic rotor model which includes anisotropic couplings. The third stage will include large deflection theory (analysis becomes nonlinear) so that bearingless rotor configurations can be modeled. The conversion and helicopter forward flight modes will also be available at this stage.

Accomplishment Description: An analysis was developed for predicting tiltrotor aeroelastic stability in high-speed axial flight. Numerical studies were developed using, as a baseline configuration, the Bell 25-ft diameter proprotor cantilever wing model. Rotor flap and lag frequency, wing stiffnesses, wing sweep, and Lock number were some of the key design parameters varied to determine respective contributions to aeroelastic stability. The basic rotor and wing motions, which are strongly coupled, are illustrated in the upper left sketch. This coupling increases with air velocity through the rotor resulting in a flutter instability at some airspeed. To expand the axial flight envelope, the velocity at which the instability occurs must be increased, presenting a design problem. With increased velocity there are performance advantages in sweeping the wing forward, but, as shown in the lower left sketch, the flutter velocity tends to decrease significantly with forward wing sweep. The upper right sketch illustrates that the flutter speed can be increased with an optimum lag frequency. The rotor lag motion is highly damped because of the high-inflow/high-twist configuration of the tiltrotor in axial flight. This damping can be transferred into the wing modes at some airspeed where the lag frequency coalesces with a wing frequency, resulting in a higher flutter speed. Another counter-measure for avoiding lower flutter speeds with forward wing sweep is illustrated in the lower right sketch. Here, an increase in the wing chordwise stiffness is shown to maintain the original flutter speed of the baseline configuration having no wing sweep.

Significance: This research extends the fundamental understanding of tiltrotor aeroelastic stability in high-speed flight. Particularly, the role of lag dynamics and its influence on aeroelastic stability have been neglected by many researchers in the past. The effects of forward wing sweep on stability are also significant because of recent emphasis on this type of tiltrotor configuration.

Future Plans: The present results will be presented in April 1992 in Dallas at the AIAA Structures, Structural Dynamics, and Materials Conference. Continued effort will be expended to develop the analysis method as described in the approach section.

Figure 41 (a).

PARAMETERS FOR IMPROVING TILTROTOR AEROELASTIC STABILITY IN HIGH-SPEED AXIAL FLIGHT IDENTIFIED

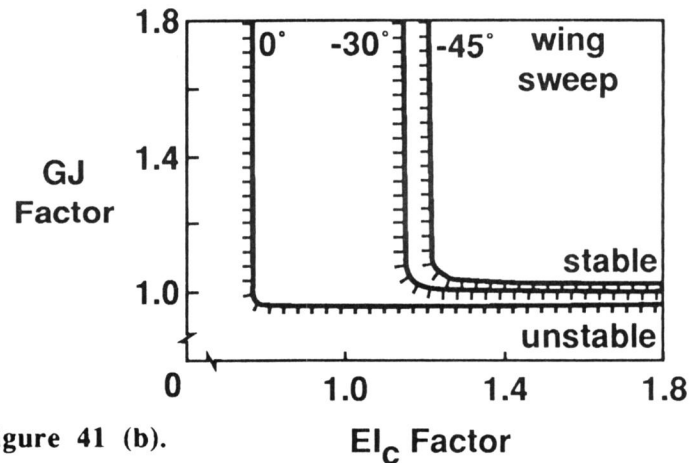
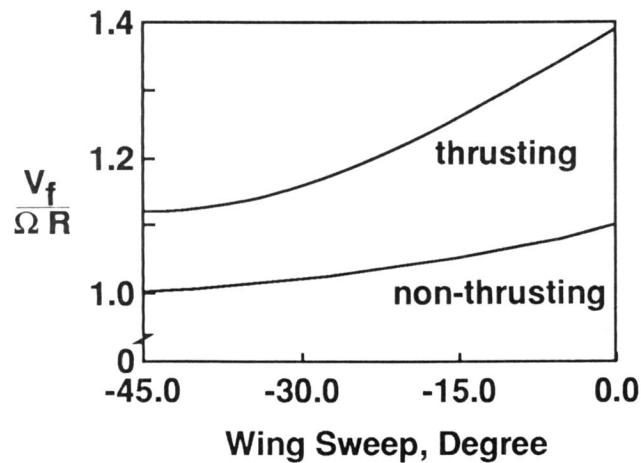
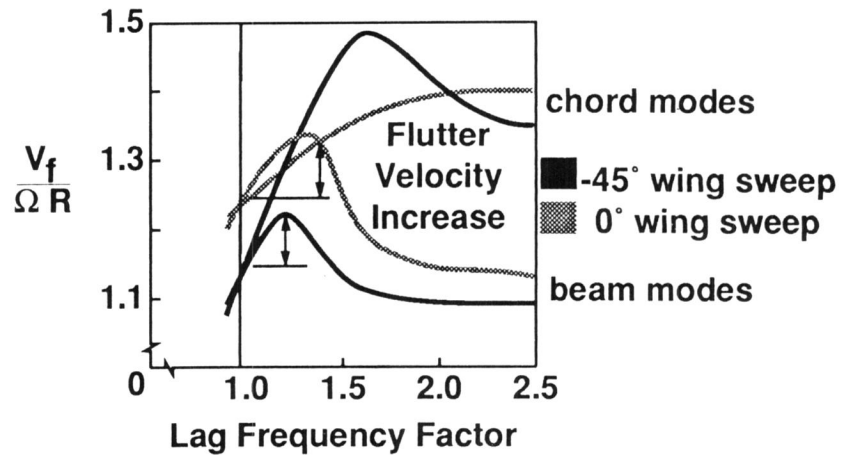
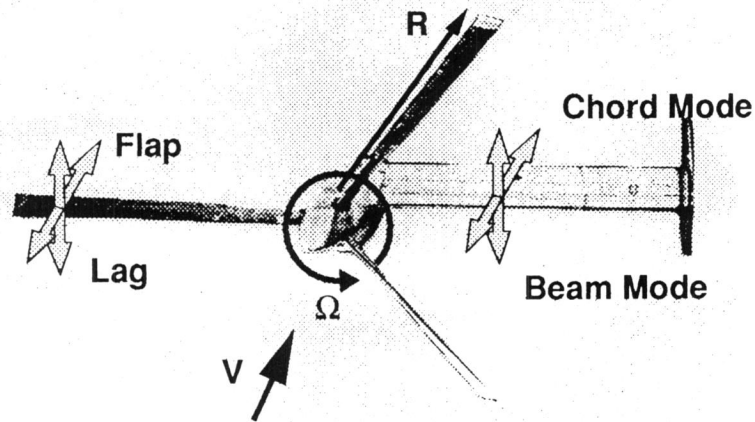


Figure 41 (b).

GEOMETRIC ENTITIES IDENTIFIED FOR USE WITH P-VERSION FINITE ELEMENT ANALYSES

Howard E. Hinnant
Aeroservoelasticity Branch

RTOP 505-63-36

Research Objective: The reduction of rotorcraft vibrations is one of the most pressing and difficult problems facing the structural dynamicist today. To have a significant impact on reducing vibration, without attendant weight or performance penalties, it is becoming increasingly important for vibration reduction to be considered during design. However, current finite element based dynamic analyses are not accurate enough to be used with confidence during design. The objective of this research effort is to develop finite element dynamic analysis methodologies which are more accurate, easier to use, and computationally more efficient.

Approach: One of the problems in both h- and p-version finite element analysis is that of maintaining continuity between adjacent elements. In one-dimensional finite elements the problem does not exist. This is because all elements are shaped like lines and interconnect only at points. The point is used in all finite element analyses to represent physical unknowns (usually displacements) at a specific location. Even in a one-dimensional p-version analysis where some of the unknowns are relegated to the interior of the line elements, interelement discontinuity does not exist. The problem appears when points are used to interconnect two-dimensional objects such as plate elements. If adjacent plate elements do not have identical shape functions along their common boundary, displacement discontinuities will arise. This typically happens in h-version codes with non-coplanar plates, and in p-version codes when the order of the element varies between adjacent elements. Following the example of one-dimensional lines being perfectly bounded by zero-dimensional points, it was decided to bound two-dimensional surfaces with one-dimensional lines. Extrapolating further, three-dimensional volumes should be bound by two-dimensional surfaces. The concept of bounding an n-dimensional object by n-1-dimensional objects for use in finite element analysis has been termed geometric entities. Geometric entities are points, lines, surfaces and volumes. They define geometry and possess degrees of freedom. Finite elements reference these objects, assume the geometry of the entities, and define mass and stiffness relationships among the associated degrees of freedom.

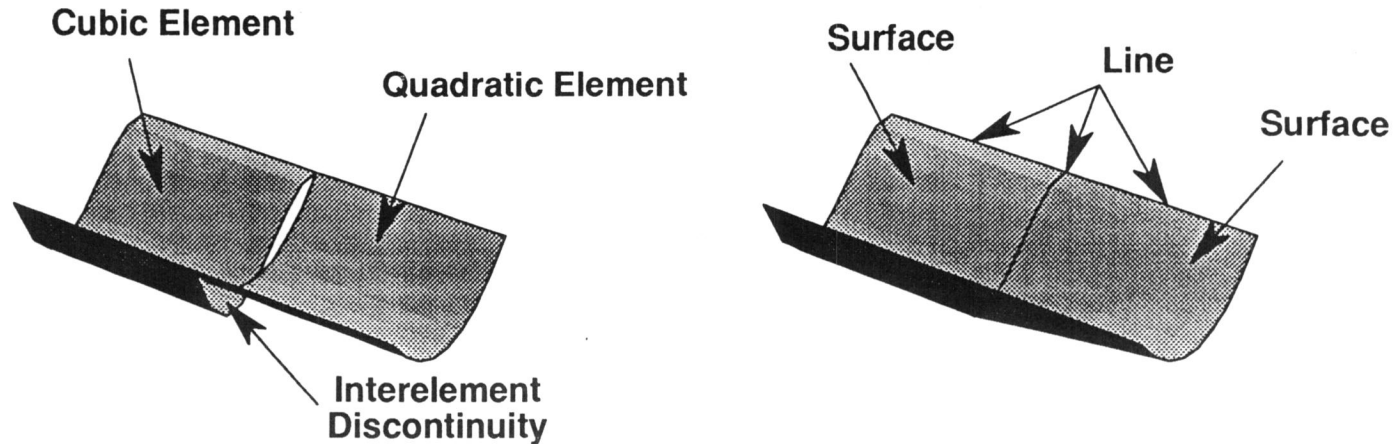
Accomplishment Description: An in-house finite element program named FEAT (Finite Element Advanced Technology) is under development. FEAT incorporates the idea of geometric entities and currently has a six sided p-version, curvilinear, anisotropic brick element. This program is being used to study the implementation aspects of geometric entities.

Significance: Using the method of geometric entities, adjacent p-version elements of differing order will maintain continuity. This is because the elements no longer have any order, only the underlying geometric entities do. Adjacent geometric entities maintain continuity because they are perfectly bounded. For example, consider two adjacent surfaces (upper or lower two sketches). The two surfaces each reference a common line or boundary between the elements. This line is capable of deforming according to its degrees of freedom. However, no matter how the line deforms, each adjoining surface will warp itself to follow that deformation. Thus there can be no discontinuity between the surfaces. Assuming that a shell element can be properly cast in the context of geometric entities, then non-coplanar shells would not exhibit the discontinuities present in mainstream finite element analyses today.

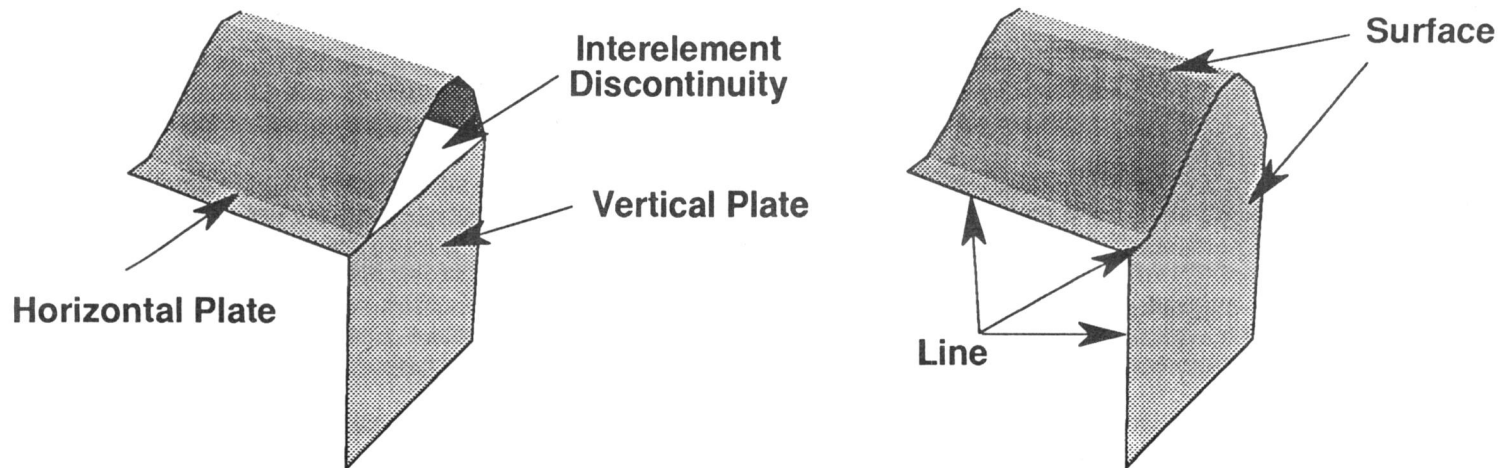
Future Plans: Future plans include the implementation of a shell element and a beam element. All elements will be completely compatible with each other in both translation and rotation. Upon achieving this, FEAT will be used to study the effects of incompatibility on current airframe finite element models.

GEOMETRIC ENTITIES IDENTIFIED FOR USE WITH P-VERSION FINITE ELEMENT ANALYSES

EXAMPLE #1: INTERACTION OF TWO HORIZONTAL PANELS



EXAMPLE #2: INTERACTION OF HORIZONTAL AND VERTICAL PANELS



Traditional Formulation

Figure 42 (b). With Geometric Entities

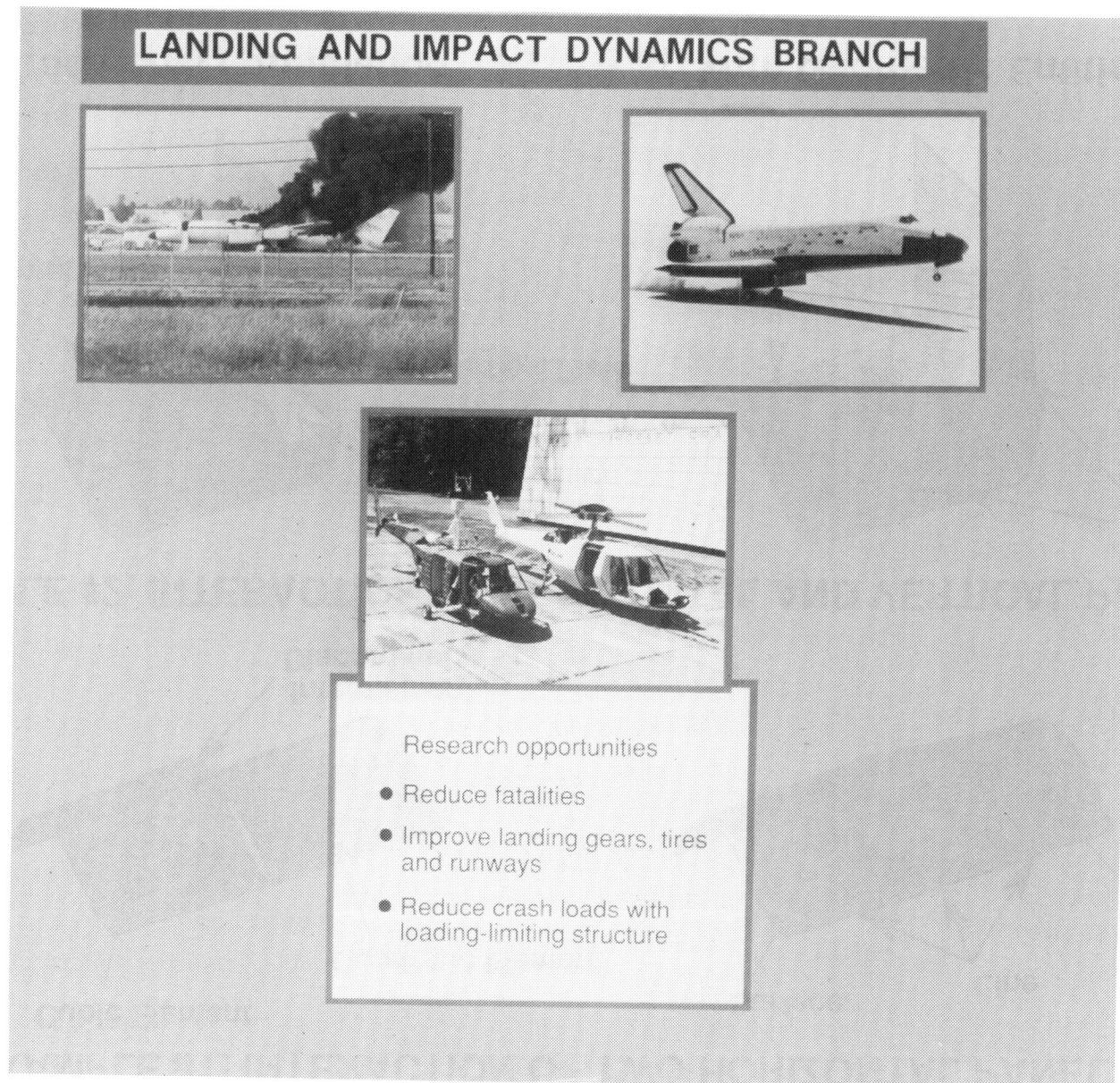


Figure 43.

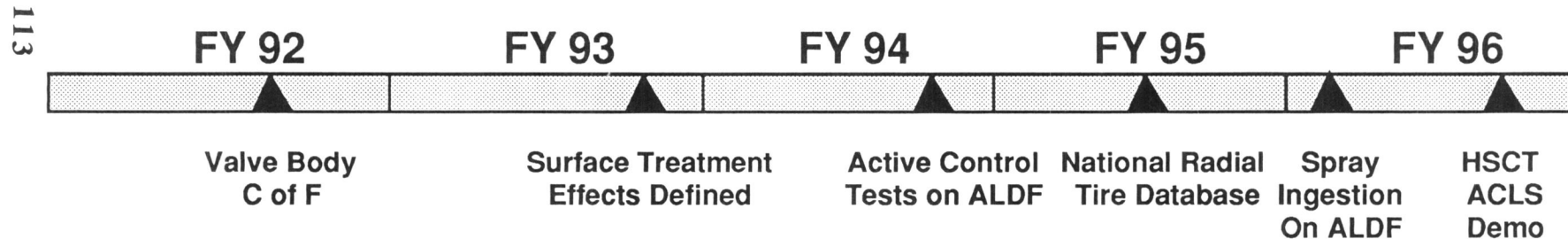
LANDING DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

ENHANCED GROUND HANDLING SAFETY AND PERFORMANCE

KEY OBJECTIVES

- CONDUCT LABORATORY AND ALDF TESTS OF NEW TIRE DESIGNS AND ACTIVE CONTROL LANDING GEAR CONCEPTS



- DEVELOP TIRE AND LANDING GEAR ANALYSIS TOOLS

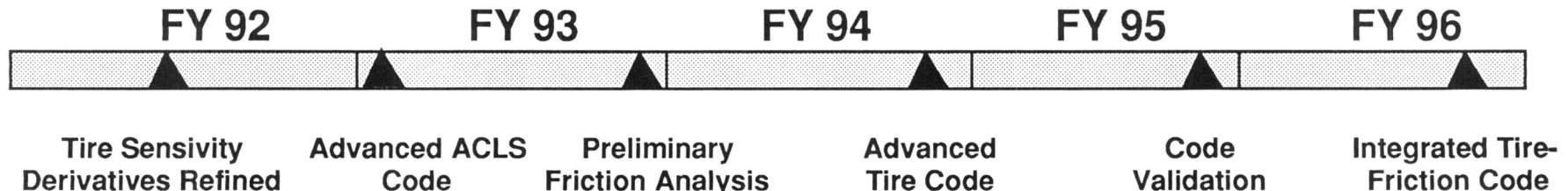


Figure 44 (a).

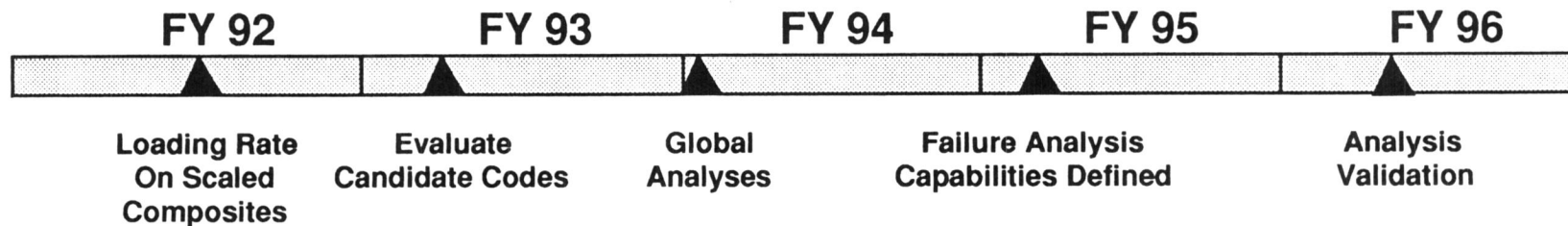
IMPACT DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

**FUNDAMENTAL UNDERSTANDING OF COMPOSITE CRASH BEHAVIOR
AND IMPROVED CRASHWORTHY DESIGNS**

KEY OBJECTIVES

● DEVELOP NONLINEAR STRUCTURAL ANALYSIS METHODS



● DEFINE DATA BASE FOR COMPOSITE STRUCTURES

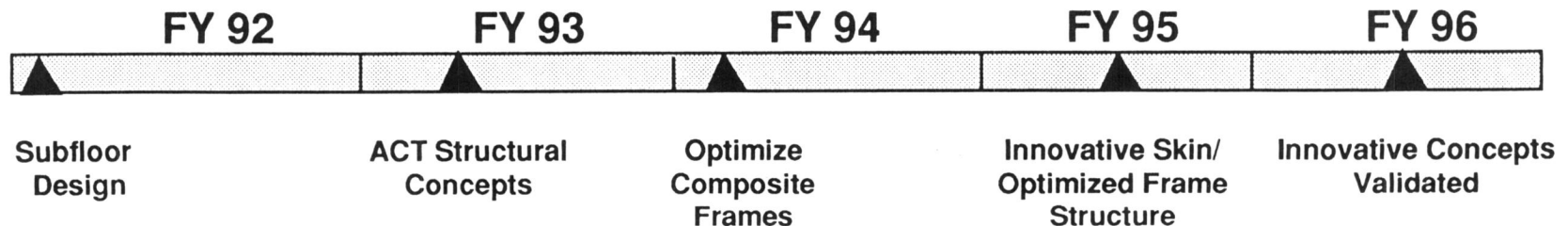


Figure 44 (b).

IMPACT DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

FUNDAMENTAL UNDERSTANDING OF COMPOSITE CRASH BEHAVIOR
AND IMPROVED CRASHWORTHY DESIGNS

KEY OBJECTIVES

- 115 ● CONDUCT FULL-SCALE TESTS OF COMPOSITE AIRFRAMES

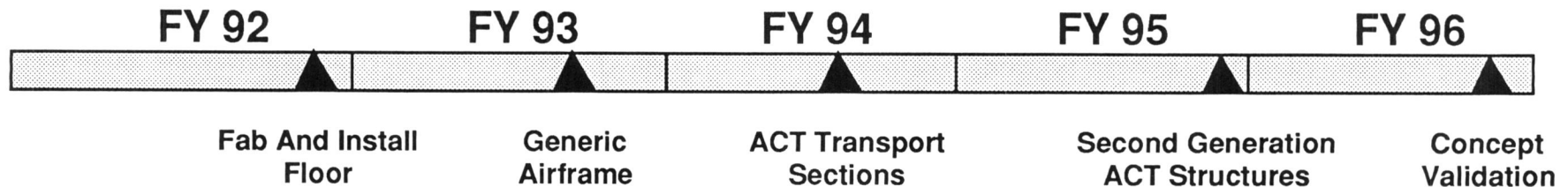


Figure 44 (c).

COMPRESSION TESTING INDICATES THAT CRUSHING BEHAVIOR OF KEVLAR/GR-EP HYBRID COMPOSITE PLATES IS INDEPENDENT OF TRIGGER MECHANISM GEOMETRY

Catherine Traffanstedt and John Morton, ESM Dept. VPI&SU, Blacksburg, VA
Karen E. Jackson and Richard L. Boitnott, U.S.Army Aerostructures Directorate

RTR 510-02-12

Research Objective: To determine the effect of trigger mechanism geometry and laminate stacking sequence on the load-deflection response, crushing behavior, and energy absorption (e/a) of flat composite plates.

Approach: Hybrid composite plates were constructed of Kevlar 49 and Graphite AS4 fibers in a 3502 epoxy resin matrix. Two laminate stacking sequences were tested. The first sequence contained blocks of graphite and Kevlar plies and is representative of a ply level fabrication method. The second sequence contained graphite and Kevlar plies distributed throughout the laminate thickness, typical of a sublamine level fabrication method. Three trigger geometries including notched, chamfer, and steeple were machined into the plate specimens to initiate crushing.

Accomplishment Description: Load-deflection plots of Kevlar/Gr-ep composite hybrid plates containing the three different trigger mechanisms are shown in the figure for both ply level and sublamine level stacking sequences. The trigger geometry affects the initial response of the plates, with the notched specimen exhibiting the highest peak load and the chamfer specimen exhibiting the lowest peak load for the ply level stacking sequence. The geometry of the trigger determines how the compressive load is introduced into the laminate. For example, loading in the notched specimens uniformly compresses the trigger region. However, the loading in the steeple and chamfer specimens first compresses only Kevlar plies, then alternates loading graphite and Kevlar plies. The small "download" observed in the initial-to-peak load regions of plates having these mechanisms may be explained by this effect. The overall differences in peak load are slight, and, accounting for slight offsets, crushing is seen to initiate at approximately the same end displacement value. The load-deflection plots of the ply level laminates, which contain discrete blocks of graphite and Kevlar plies, exhibit almost classic e/a curves in which the sustained loads remain uniform and level throughout the crushing process. Alternatively, the sublamine level stacking sequence exhibits a steady increase in load during crushing.

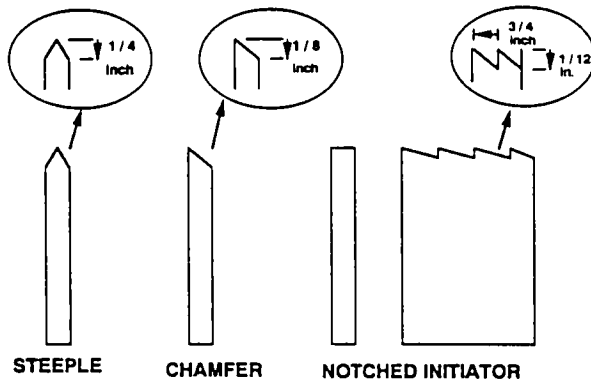
Significance: A simple and inexpensive test method was developed to determine the e/a performance of composite material systems and laminate stacking sequences. These data are extremely important in the design of crashworthy, light weight subfloors for rotorcraft and aircraft.

Future Plans: To assess the influence of the rod supports on the load-deflection response and e/a performance of Kevlar/Gr-ep hybrid plates. Also, a modified test fixture is required to permit testing of more realistic "J" trigger mechanisms which are typical of cruciform sections.

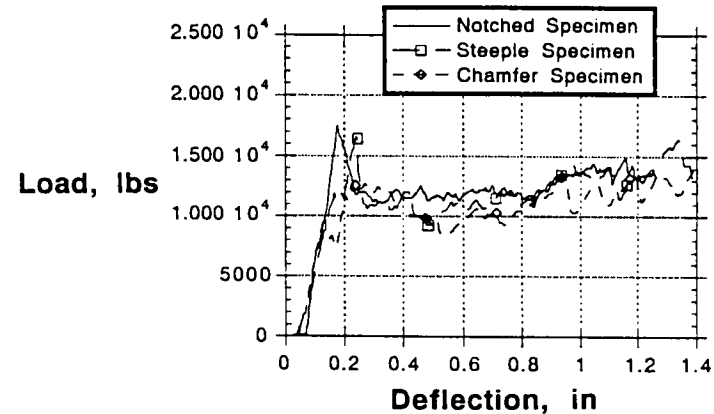
Figure 45 (a).

COMPRESSION TESTING INDICATES CRUSHING BEHAVIOR OF KEVLAR/GR-EP HYBRID COMPOSITE PLATES IS INDEPENDENT OF TRIGGER MECHANISM GEOMETRY

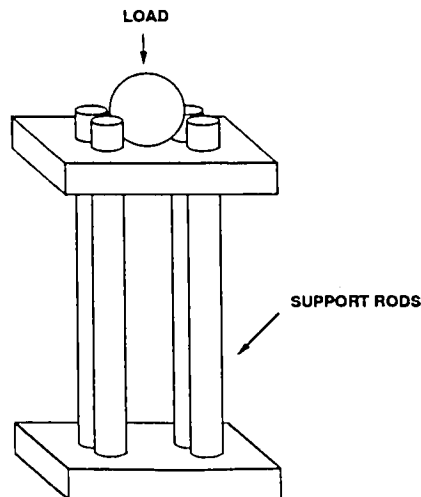
TRIGGER MECHANISMS



PLY LEVEL STACKING SEQUENCE [± 45 K₂ / 0 GR₈ / ± 45 K₂] s



SCHEMATIC OF TEST FIXTURE



SUBLAMINATE LEVEL STACKING SEQUENCE [± 45 K / 0 GR₄ / ± 45 K) 2] s

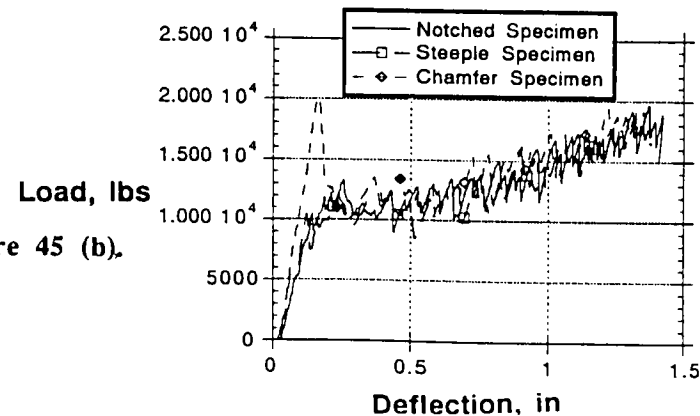


Figure 45 (b).

SCALING OF ENERGY ABSORBING COMPOSITE PLATES DEMONSTRATED THROUGH COMPRESSION TESTING

Catherine Traffanstedt and John Morton, ESM Dept. VPI&SU, Blacksburg, VA
Karen E. Jackson and Richard L. Boitnott, U.S.Army Aerostructures Directorate

Landing and Impact Dynamics Branch RTR 510-02-12

Research Objective: To study scaling effects in the crushing behavior and energy absorption (e/a) of hybrid Kevlar/Graphite-epoxy composite plates which were constructed using both ply level and sublamine level fabrication techniques.

Approach: Half and full scale composite plates were selected for testing. Full scale plates were fabricated using both ply level and sublamine level scaling techniques. A graphite-Kevlar hybrid was chosen to maximize structural integrity and energy absorption. The laminate stacking sequences are $[\pm 45 \text{ K} / 0 \text{ GR4} / \pm 45 \text{ K}]_s$ for the half scale or baseline plate, and $[(\pm 45 \text{ K}_2 / 0 \text{ GR8} / \pm 45 \text{ K}_2)]_s$ for the full scale plate (ply level scaling), and $[(\pm 45 \text{ K} / 0 \text{ GR4} / \pm 45 \text{ K})_2]_s$ for the full scale plate (sublamine level scaling). Three trigger mechanisms including notched, chamfer, and steeple were machined into the plate specimens to initiate crushing; however, only the chamfer specimen results are presented here.

Accomplishment Description: Approximately seventy static tests were conducted on half and full-scale hybrid plates, with typically six replicate tests performed for a given plate size and trigger geometry. Comparisons of the load-deflection response of the baseline, or half scale, composite plate with the full-scale ply level and sublamine level plates are shown in the figure. The load and deflection data from the full scale test were multiplied by the appropriate factor to "scale down" the response for comparison with the half scale data. As shown in the figure, a high degree of similarity exists between the load-deflection responses of the half and full-scale specimens. Initial load response, peak load, and sustained crushing load agree to within 20 per cent. The ply level full-scale plate failed in a manner very similar to the baseline plate and exhibited a relatively flat load-deflection curve during crushing. Alternatively, the sublamine level stacking sequence exhibited a steady increase in load during crushing. This phenomenon may be due to frictional loads generated by debris build-up as the specimen crushes.

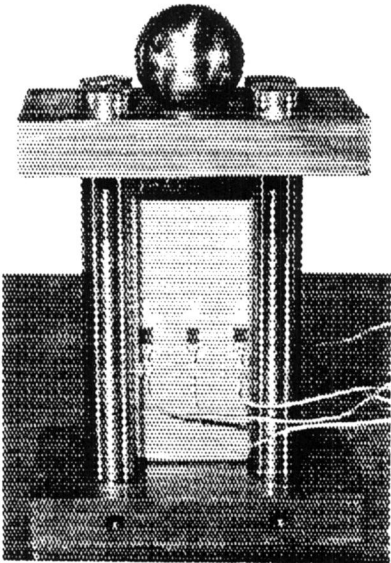
Significance: It is necessary to examine the feasibility of using scale model testing for determining the e/a performance of composite materials for application in crashworthy rotorcraft and aircraft subfloor structures. Validated experimental results from sub-scale testing will save cost and permit more extensive testing of preliminary designs.

Future Plans: To assess the influence of the rod supports on the load-deflection response and e/a performance of Kevlar/Gr-ep hybrid plates. Also, a modified test fixture is required to permit testing of more realistic "J" trigger mechanisms which are typical of cruciform sections. Analytical modeling of the load-deflection response will be pursued.

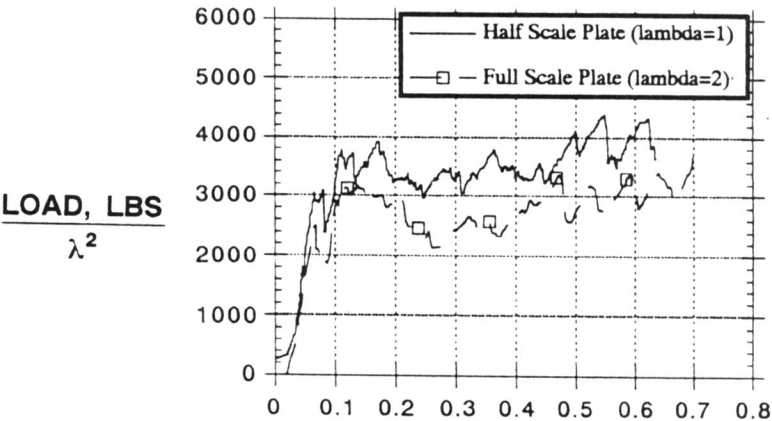
Figure 46 (a).

SCALING OF ENERGY ABSORBING COMPOSITE PLATES DEMONSTRATED THROUGH COMPRESSION TESTING

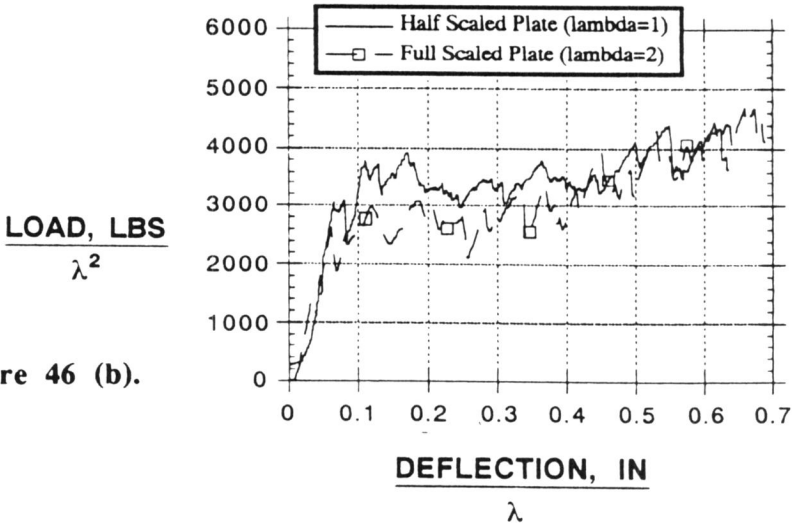
PHOTO OF PLATE SPECIMEN
IN TEST FIXTURE



CHAMFER BASELINE AND
PLY-LEVEL FULL SCALE



CHAMFER BASELINE AND
SUBLAMINATE FULL SCALE



TRIGGER MECHANISM

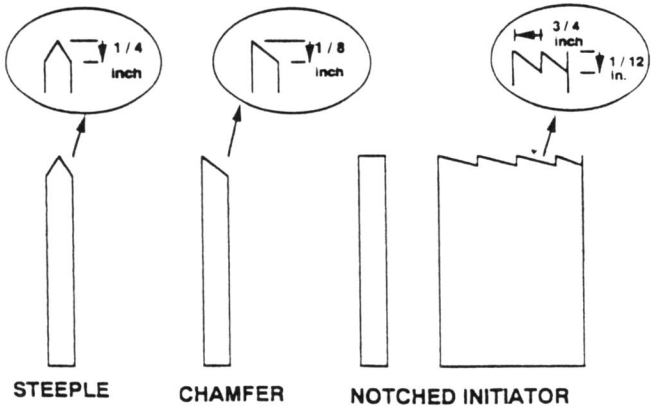


Figure 46 (b).

STRENGTH SCALING OF $\pm 45^\circ$ ANGLE PLY LAMINATES IDENTIFIES NEED FOR MORE PRECISE SPECIFICATIONS IN ASTM TESTING STANDARDS

Sotiris Kellas, ESM Department, VPI&SU, Blacksburg, VA
Karen E. Jackson, U.S. Army Aerostructures Directorate

Landing and Impact Dynamics Branch
RTR 510-02-12

Research Objective: To study factors responsible for scale effects in the tensile strength of angle ply graphite/epoxy composite laminates.

Approach: Two generic $\pm 45^\circ$ lay-ups were studied, one with blocked plies and one with distributed plies with stacking sequences containing between 8 and 32 plies. A graphite-epoxy system (AS4/3502) was used to fabricate six "scaled-up" laminates with the following stacking sequences; $(+45^\circ_n/-45^\circ_n)_2S$ (blocked plies) and $(+45^\circ/-45^\circ)_{2nS}$ (distributed plies), where $n = 2, 3$, and 4 . Tensile coupon specimens having four scaled sizes were constructed including full scale size, $3/4$, $2/4$, and $1/4$, corresponding to n equal 4 , 3 , 2 , and 1 , respectively.

Accomplishment Description: Both blocked and distributed angle ply laminates exhibit scaling size effects in which the stress/strain response and ultimate strength are dependant upon the generic stacking sequence and the specimen thickness. Geometrically scaled tensile coupons with blocked plies, those scaled on a ply level, exhibit brittle behavior and reduced strength with increasing specimen size, as shown in the attached figure. Conversely, laminates with distributed plies, those scaled on a sub-laminate level, exhibit ductile behavior and increased strength with increasing specimen size. Also, the strength of a distributed ply laminate is greater than that of a corresponding blocked ply laminate for a given specimen size. It was found that the relative ply thickness of the surface plies, where damage initiates, is one of the most important factors that controls the stress/strain response and the strength of angle ply laminates. The development of a transverse matrix crack in a blocked ply laminate results in a greater loss of stiffness and strength than a similar crack in a distributed ply laminate.

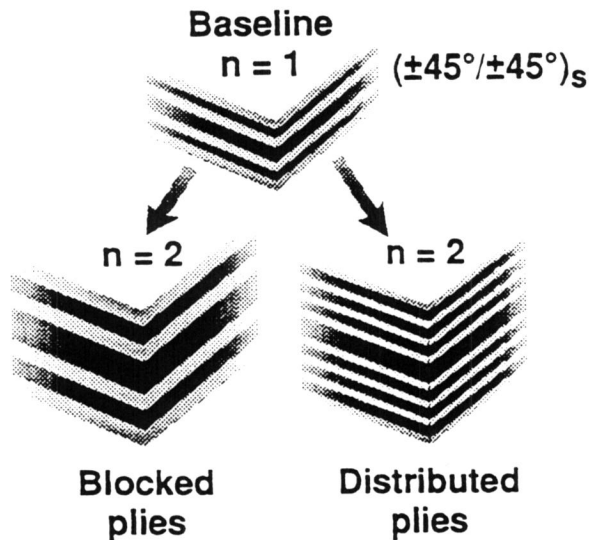
Significance: ASTM standard tests for determination of the in-plane shear stiffness and strength are based on $\pm 45^\circ$ angle ply testing, although exact specifications for the laminate stacking sequence are not stated. Results of this research show that the values of strength can vary tremendously depending on whether the laminate stacking sequence contains blocked or distributed plies. In addition, the size of the laminate, especially the number of plies, is important. Recommendations to improve the standard testing practices have been made to the ASTM so that a meaningful shear strength value, independent of specimen size, can be determined from tensile tests on $\pm 45^\circ$ laminates.

Future Plans: Similar tests will be carried out on scaled laminates with different generic lay-ups and comparisons will be made with blocked and distributed ply laminates. In addition, tests will be repeated using a more ductile composite material system (AS4/PEEK).

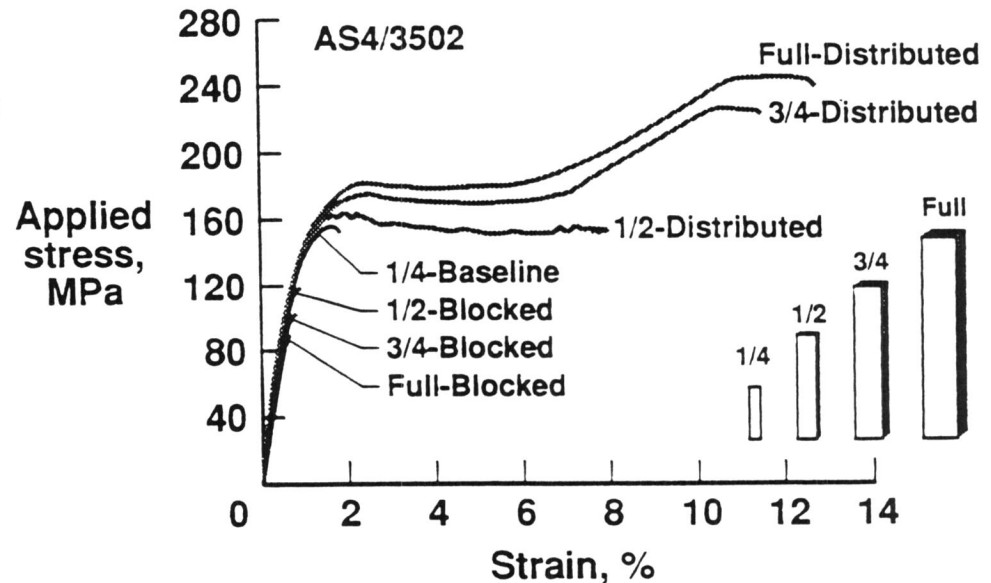
Figure 47 (a).

Strength Scaling of $\pm 45^\circ$ Angle Ply Laminates Identifies Need for More Precise Specifications in ASTM Testing Standards

Thickness Scaling Methods



Stress/Strain Response



- For increasing specimen size
 - Strength decreased for blocked ply laminates
 - Strength increased for distributed ply laminates
 - Strength of distributed laminates is greater than blocked laminates for a given specimen size
- Need exists for improved ASTM specifications for coupon size & stacking sequence for proper determination of composite shear strength

Figure 47 (b).

REDUCED BASIS TECHNIQUE DEVELOPED FOR PREDICTING THE NONLINEAR VIBRATIONAL RESPONSE OF COMPOSITE STRUCTURES

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Center for Computational Structures Technology
University of Virginia

RTOP 505-63-50

Research Objective: The objective of this research is to develop an efficient reduced basis technique and a computational procedure for predicting the nonlinear, large-amplitude, vibrational response of composite airframes.

Approach: A two-phase hybrid computational procedure has been developed for the predictions of the nonlinear vibrational response of structures. The first phase involves determination of the linear free vibration frequencies and mode shapes by solving a linear eigenvalue problem. For each pair of eigenvalue-eigenvector, Linstedt-Poincare method is used to generate perturbation vectors. In the second phase, the perturbation vectors are selected as basis vectors and the Rayleigh-Ritz technique is applied to generate a set of reduced nonlinear algebraic equations, which approximate the governing equations of the structure. The unknowns in the reduced equations are the amplitudes of the basis vectors and the nonlinear frequency of vibration.

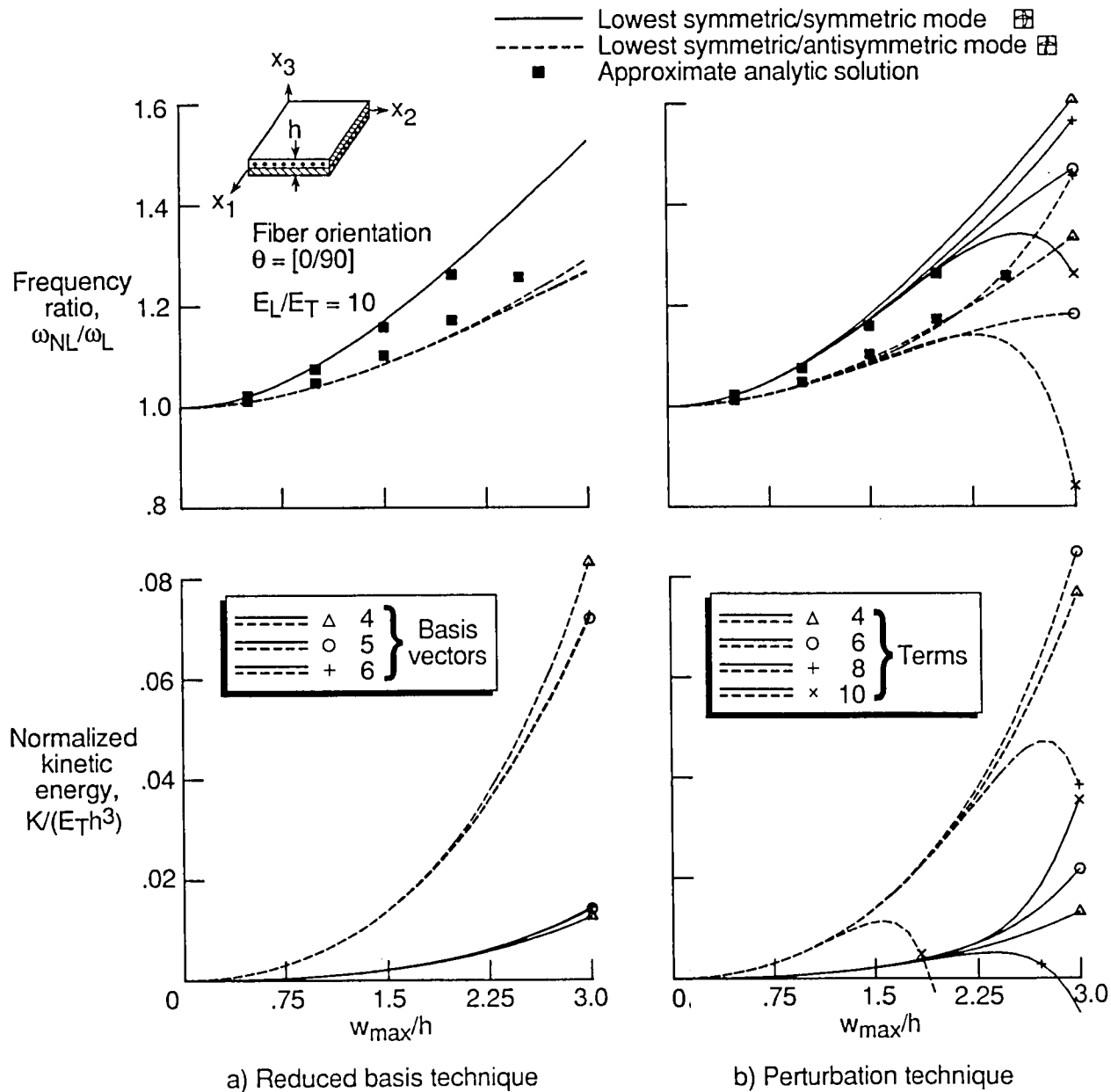
Accomplishment Description: The procedure has been applied to multilayered composite panels, and to thin-walled beams. In the attached figure comparisons are made between the nonlinear frequencies and kinetic energies, associated with the first symmetric/symmetric and symmetric/antisymmetric modes, obtained by the proposed technique to those obtained by the perturbation technique. The frequencies obtained by an approximate analytical technique based on the combined application of the Bubnov-Galerkin and harmonic balance techniques, are shown in the figure. The rapid convergence of the solutions obtained by the reduced basis technique, for amplitudes up to three times the thickness of the plate, $w/h = 3.0$, is demonstrated. The perturbation solutions diverge for $w/h > 1.5$.

Significance: The technique developed will allow the detailed study of nonlinear, large-amplitude vibrational response of composite airframes. Higher degree of geometric nonlinearity can be handled than has been done by perturbation techniques. Also, modal coupling can be easily investigated.

Future Plans: The technique will be further refined to improve its efficiency and to allow conducting extensive parametric studies for composite airframes. Results of the numerical simulation will be compared with the experiments performed at the Landing and Impact Dynamics Branch. Also, the range of validity of the geometrically nonlinear thin-walled beam model will be identified in terms of the various geometric and material parameters of the frame.

Figure 48 (a).

REDUCED BASIS TECHNIQUE DEVELOPED FOR PREDICTING THE NONLINEAR VIBRATIONAL RESPONSE OF COMPOSITE STRUCTURES



MACINTOSH BASED DAS PROVIDES FOR QUICK ANALYSIS OF AIRCRAFT CRASH DATA

Edwin L. Fasanella, Lockheed Engineering and Sciences Co.
Karen E. Jackson, US Army Aerostructures Directorate
Landing and Impact Dynamics Branch, SDyD

RTOP 505-63-50

Research Objective: The purpose of this work was to assemble and customize a versatile state-of-the-art graphics based PC digital data acquisition system for quasi-static and dynamic testing at the Impact Dynamics Research Facility (IRDF) .

Approach: Since aircraft crash research was initiated at the IRDF, a tape-based analog data acquisition system has been used to record both transient (crash) and quasi-static tests for up to 90 channels of data. This analog system required two or more days turn-around time for the data to be reduced and plotted as time histories in engineering units. The analog tapes are FM multiplexed and require the Central Data Transcription Facility (CDTF) at ACD to generate digital computer tapes. The digital tapes are then read onto the computer network, and the data reduced and plotted in engineering units by the data reduction contractor. This system required a minimum two day turn-around for data plots. With the proposed closing of CDTF, an alternative digital computer based system was needed. A Macintosh PC digital data acquisition system with Labview 2 software was assembled and programmed to provide instant access of the data. This new digital system will allow quasi-static testing for 128 channels, dynamic testing for 64 channels, and also can be used to digitize the FM analog tapes of the old system. The Labview 2 software allows the creation of "virtual instruments" that are displayed graphically on the screen with buttons and knobs that are manipulated with the mouse with the "feel" of a physical instrument. The Labview environment is extremely easy to use.

Accomplishment Description: A 128 channel (expandable to 256) Macintosh FX digital data acquisition system using LabView 2 software has been developed. The hardware consists of an internal 12 bit, 16 channel A/D board capable of 100K samples/sec, up to 4 multiplexer boards, and a 32 bit DMA controller card that accesses the full NuBus address space and can handle data rates up to 1 Mbytes/sec. The system uses Labview 2 software that is user friendly with a familiar instrument type interface. Dynamic data may be collected for 64 channels with sample rates up to 1 K samples/sec per channel, or 128 channels if 500 samples/sec is sufficient. A postprocessor has been developed using the same LabView software (see figure). The postprocessor graphs any data channel with windows to enter the engineering zero and calibration. Up to 8 plots can be viewed on one screen. Switches can engage a low pass butterworth filter with selectable cutoff frequency and one allow writing to an ASCII file for exporting and simultaneously shows the data in a window with a scroll bar. Integral of acceleration (velocity) is also calculated and shown above the acceleration data trace.

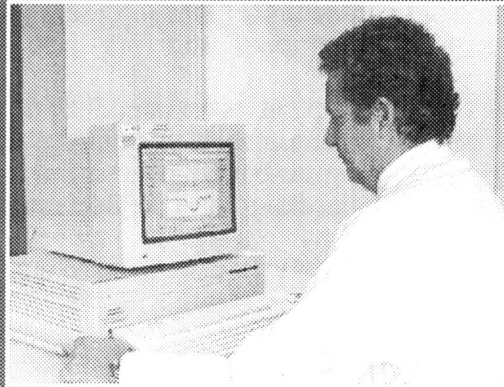
Significance: The PC digital data acquisition system has made near instant viewing of engineering data a reality. The instant data review feature has already been beneficial as a test-fixture anomaly was corrected after viewing the data from a recent test. Previously, several days could have been lost before the problem was identified and other tests could have been performed with an incorrect test set-up.

Future Plans: Upgrade hardware to 30 K samples/sec/channel for 96 channels. Document the work with a user's manual.

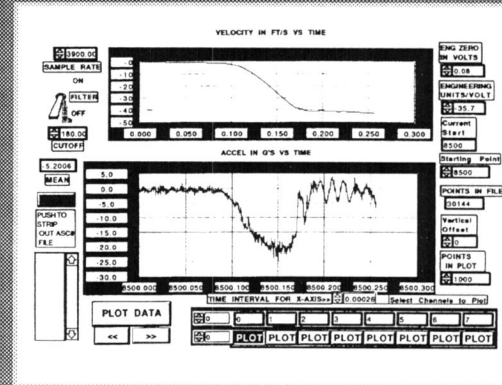
Figure 49 (a).

MACINTOSH BASED DAS PROVIDES FOR QUICK ANALYSIS OF AIRCRAFT CRASH DATA

PC aquisition system



Typical screen



Features of system

- Up to 128 channels of data can be acquired
- Sample rate 62500/N per second (N=number channels)
- Any data channel can be plotted, up to eight plots may be viewed at once
- Plot any portion of data, any starting point
- Computes average of points plotted
- Low pass Butterworth filter can be turned on or off
- Engineering units/volt and zero offset can be input
- Plotted data can be written to an ASCII file for export
- Acceleration can be integrated to give velocity

Figure 49 (b).

AIR FORCE F-111 RECOVERY PARACHUTE MODIFICATION PROGRAM SUPPORTED BY TESTING AT THE IMPACT DYNAMICS RESEARCH FACILITY

Lisa E. Jones and Huey D. Carden
Landing and Impact Dynamics Branch

Edwin L. Fasanella
Lockheed Engineering and Sciences Company
RTR 505-63-50

Research Objective: The purpose of this research was to qualify a new impact attenuation bag (IAB) for use on the F-111 aircraft through drop tests at the Impact Dynamics Research Facility (IDRF).

Approach: The F-111 Recover Parachute Modification is a critical USAF safety modification designed to reduce/eliminate the 30 percent back injury rate suffered by F-111 crew members due to high descent rate and resulting landing impact of the ejected crew module. NASA Langley had a key role in the modification development through drop testing of the F-111 crew module to determine the impact forces on the module using the newly designed impact attenuation bag (IAB). A series of drop tests of the module under various impact attitudes typically expected for the module were conducted by NASA personnel at the IDRF in support of the Air Force program.

Accomplishment Description: A series of twelve drop tests were conducted with the F-111 crew module. Five of the drop tests generated a data base on the performance of the old IAB design as a base line for comparison with the new bag design. Seven drop tests were also conducted with the new IAB design for comparison with the older design and to determine the dynamic response index (DRI) for qualifying the rate of expected injury and evaluating the development and qualification of the IAB. Accelerations, velocity, and film data were obtained on the F-111 IAB systems at the IDRF under an extremely tight, externally imposed time schedule. Sixteen channels of acceleration data along with various high speed camera and video coverage for each test were obtained, reduced and supplied to AF personnel for evaluation.

Significance: The F-111 crew module equipped with the IAB is shown in the attached figure along with typical vertical acceleration data on the Pilot seat. As may be noted, the new attenuation bag provided lower seat acceleration at a higher impact velocity than the old bag design, thus providing an increased margin of safety from potential back injury during an impact landing of the module. The extensive data obtained during the IAB drop tests with the F-111 crew module will be thoroughly evaluated to assure that the new IAB system provides the desired improvements in reduced injury to the crew members.

Future Plans: Include the data from the F-111 Recovery Parachute Modifications Program in a NASA report covering facility capability and usage.

Figure 50 (a).

AIR FORCE F-111 RECOVERY PARACHUTE MODIFICATION PROGRAM SUPPORTED BY TESTING AT THE IMPACT DYNAMICS RESEARCH FACILITY

F-111 CREW MODULE WITH AIR BAG

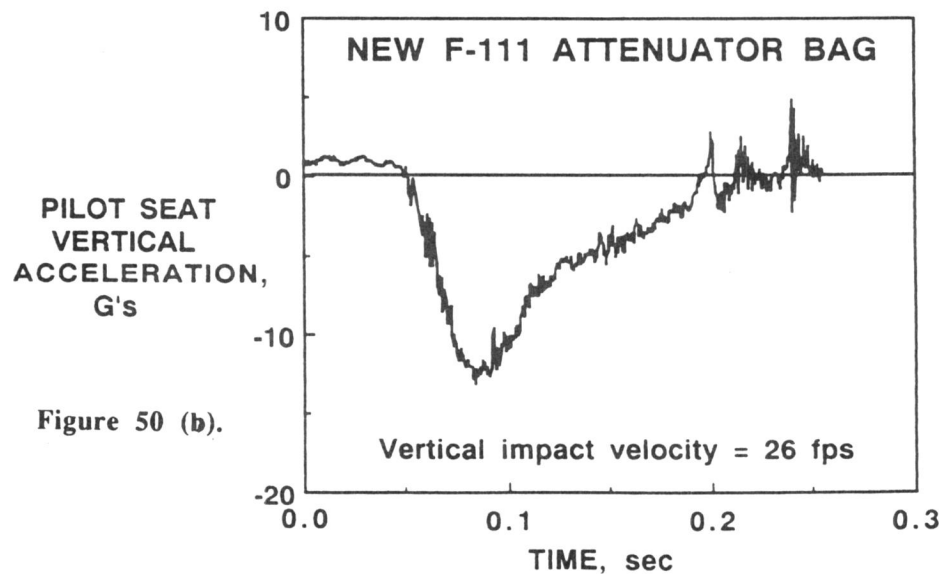
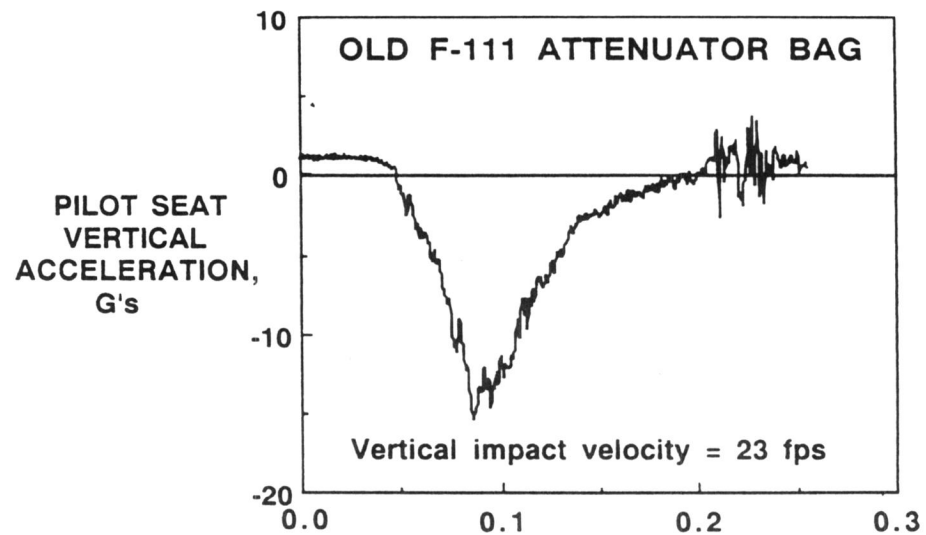
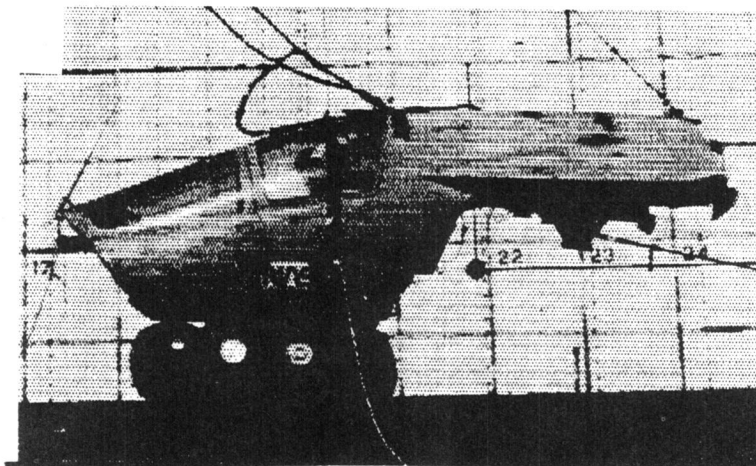


Figure 50 (b).

EFFECTS OF YAW ANGLE AND VERTICAL LOAD ON CORNERING PERFORMANCE FOR 26X6.6 BIAS-PLY AND RADIAL-BELTED TIRES ON A WET SURFACE

Pamela A. Davis, Sandy M. Stubbs, Veloria J. Martinson, and Thomas J. Yager
Landing and Impact Dynamics Branch

RTOP 505-63-10

Research Objective: The research objective is to study basic runway surface traction characteristics by using radial-belted, H-type, and bias-ply aircraft tires on different runway surface conditions, including surface grooving and environmental contaminants.

Approach: Three different tire types and three different tire sizes are being tested at the Aircraft Landing Dynamics Facility (ALDF). These tires are being tested at various speeds on a smooth ungrooved concrete runway under dry and wet surface conditions. Load-deflection, braking and cornering tests are being conducted to define the mechanical properties and friction characteristics of the different tire types and sizes.

128

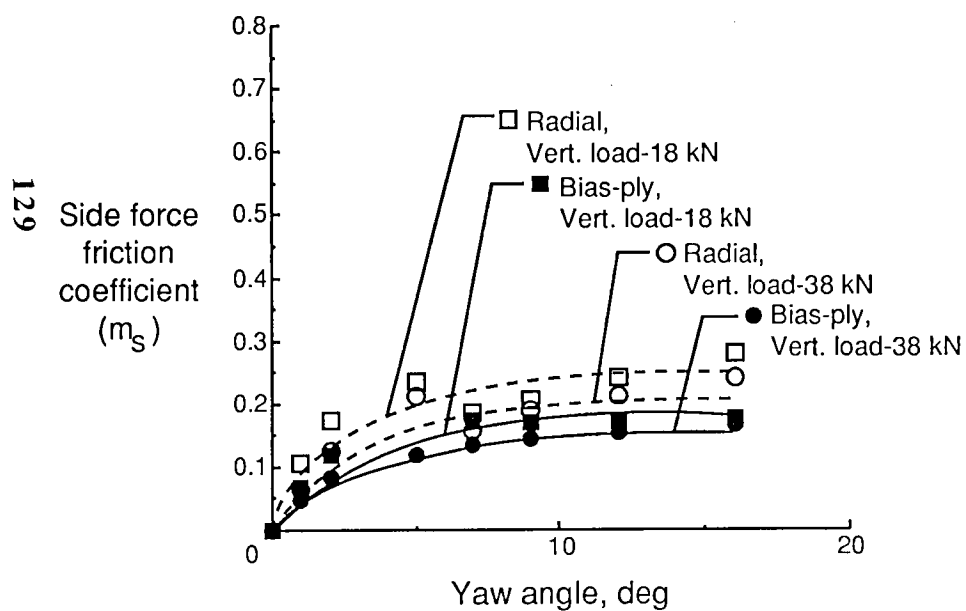
Accomplishment Description: The 26 X 6.6 size tire, which is the nose-gear tire for the McDonnell-Douglas MD-80 series airplane, has been tested in a bias-ply and radial-belted design at the ALDF. Both static load-deflection tests and cornering tests have been conducted. The cornering characteristics of these tires on a wet runway at 100 and 160 knots are shown in the attached figure for a range of vertical loads. At 100 knots, both tires were effected equally by the variation in vertical load; whereas at 160 knots, the radial tire is effected to a greater extent than the bias-ply tire by this vertical load variation. The radial tire gave higher cornering-force friction coefficients than the bias-ply tire on a wet surface at 100 and 160 knots at all loads and yaw angles tested. These results indicate that under crosswind landing conditions on a wet runway surface the radial tire would provide more friction between tire and pavement than the bias-ply tire. This may be attributed to the tire tread patterns which for the radial tire enhance its wet cornering performance.

Significance: The information shown in the attached figure will help to establish a national database for radial-belted and H-type aircraft tires that will be used to compare their mechanical property and friction characteristics with those of bias-ply tires. These data will eventually be used to enhance aircraft safety during ground operations under adverse weather conditions.

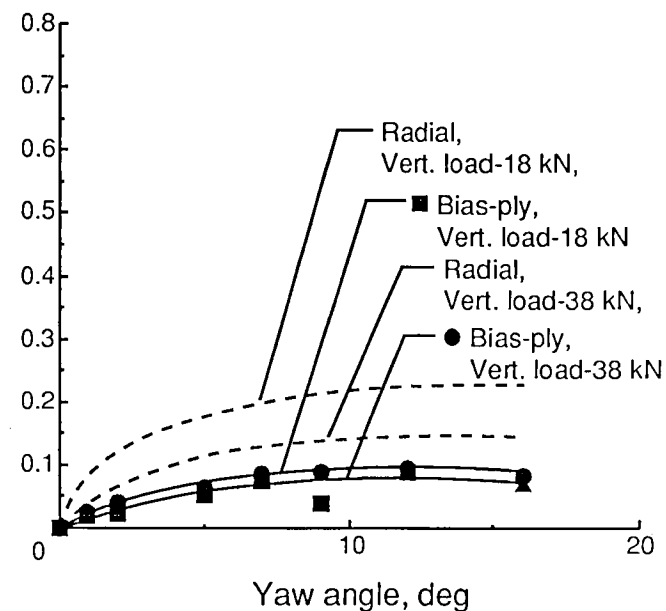
Future Plans: Future tests will be conducted with a wide-body transport main-gear tire on an ungrooved runway. The various radial-belted and H-type tires will be tested on a grooved concrete runway in order to establish the effect of pavement texture variations on tire performance. This information will be documented in a reference publication to be used as a landing gear design guide.

Figure 51 (a).

EFFECTS OF YAW ANGLE AND VERTICAL LOAD ON CORNERING PERFORMANCE FOR 26X6.6 BIAS-PLY AND RADIAL-BELTED TIRES ON A WET SURFACE



(a) Speed-100 kts



(b) Speed-160 kts

Figure 51 (b).

LaRC TESTS DEMONSTRATE SUPERIOR WEAR PERFORMANCE OF MODIFIED SPACE SHUTTLE MAIN-GEAR TIRE

Robert H. Daugherty and Sandy M. Stubbs

Landing and Impact Dynamics Branch

RTOP 505-63-10

Research Objective: To increase the tread life of the Space Shuttle orbiter so that the safety margins associated with crosswind landing operations at KSC are significantly improved.

Approach: The high landing speeds of the Space Shuttle coupled with the highly textured runway surface on the Shuttle Landing Facility, have resulted in excessive Shuttle main-gear tire wear during landing operations at KSC. Grinding the runway surface smooth is not an option since this could lead to tire hydroplaning during wet landing operations. An alternate approach has been to modify the Shuttle main-gear tire to improve tread life.

Accomplishment Description: The figure shows the cross sections of the baseline and modified tires. The modified tire has an extra 0.1 in. of undertread rubber to absorb wear and the rubber composition is 65 percent natural rubber and 35 percent synthetic rubber whereas the baseline tire has a 100 percent natural rubber tread. The spin-up wear on the baseline tire subjected to a 200 knot touchdown on a corduroy runway surface destroys about two-thirds of the tread depth whereas the spin-up wear on the modified tire under identical conditions destroys only one-sixth of the tread depth as denoted by the green cross hatch in the figure. Both tires will fail when the carcass has been worn through 11 cords as denoted by the red cross hatch. The wear associated with tire cornering effort is plotted as a function of side energy in the figure. The baseline tire will be worn through six cords (the maximum allowable wear limit) after the tire has dissipated approximately 2.5 million ft-lb of side energy as indicated by the solid blue line. The modified tire, on the other hand, will be worn to the same limit after it has dissipated more than 8.5 million ft-lb of side energy as denoted by the dashed line. This represents an improvement in tread life for the Space Shuttle orbiter main-gear tire of better than 300 percent over the current baseline tire.

Significance: A 15-knot crosswind landing (the current Space Shuttle crosswind limit based on allowable tire wear) will expose each main-gear tire to 2- to 2.5 million ft-lb of side energy. A 20-knot crosswind landing (the original orbiter crosswind limit) will expose each main-gear tire to approximately 4 million ft-lb of side energy. The data in the figure indicate the the modified tire can easily handle a 20-knot crosswind landing at KSC.

Future Plans: As a result of the marked improvement in tread life of the modified tire over the baseline tire, the Shuttle Project Office is accelerating the certification tests for the modified tire so that it will be ready for installation on the orbiter for STS-45.

Figure 52 (a).

LaRC TESTS DEMONSTRATE SUPERIOR WEAR PERFORMANCE OF MODIFIED SPACE SHUTTLE MAIN-GEAR TIRE

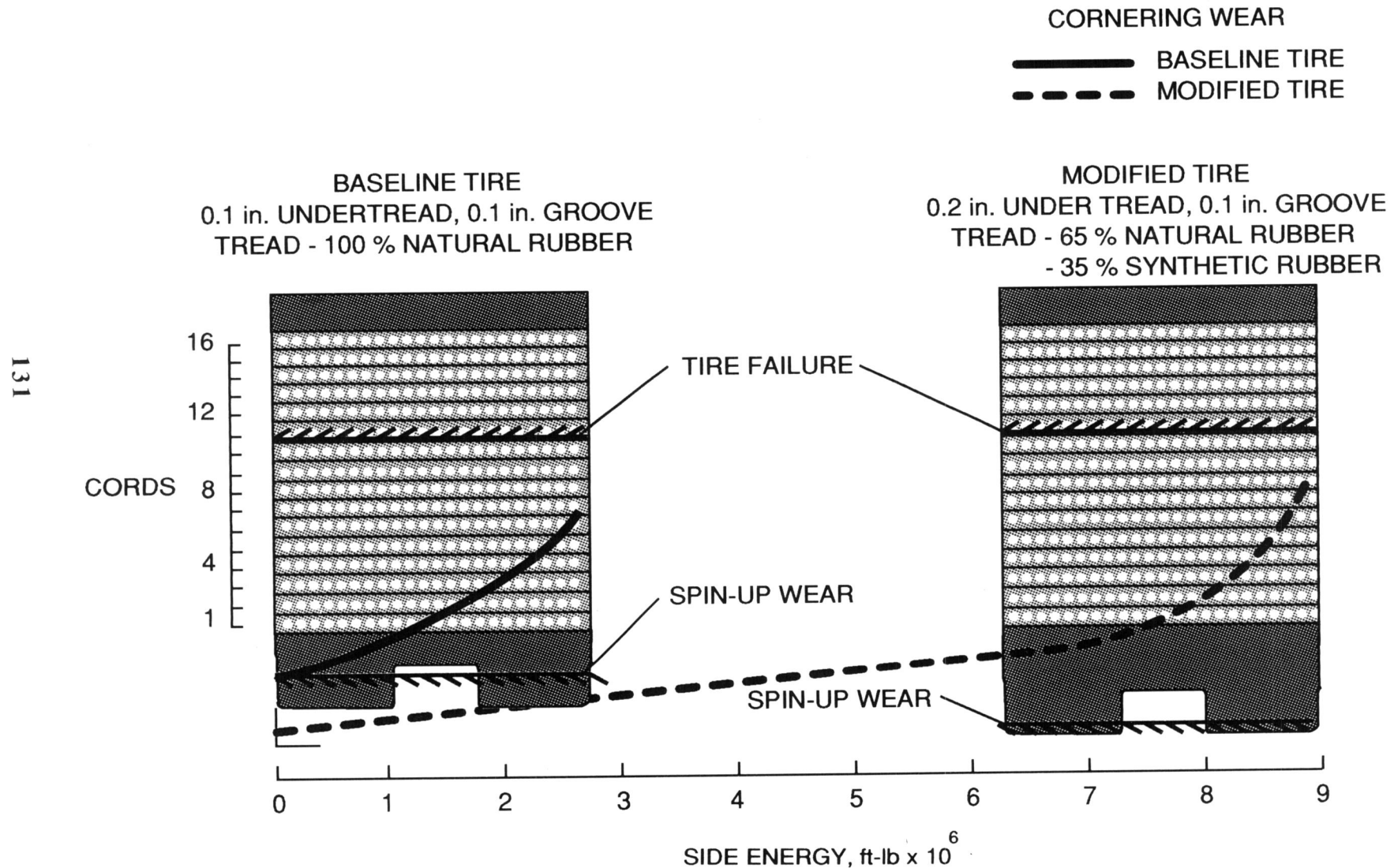


Figure 52 (b).

NATIONAL TIRE MODELING CODE (TIRE-3D) DISTRIBUTED TO INDUSTRY

John A. Tanner

Landing and Impact Dynamics Branch,

RTOP 505-63-10

Research Objective: The purpose of the National Tire Modeling Program (NTMP) is to develop tire modeling technology that will keep the U.S. tire industry competitive in the worldwide market place.

Approach: The NTMP is a joint effort between NASA and the U.S. tire industry to develop a family of tire modeling computational procedures and algorithms and to provide a national database of measurements of tire responses to various loading conditions. The resulting tire modeling code (TIRE-3D) was developed under contract by The Computational Mechanics Company, Inc. and has been released to the participants of the NTMP. The experimental database was developed through in-house and industry tests to define the response characteristics of automotive and aircraft tires to a set of benchmark loading conditions. These experimental results are being used to validate the analytical results from TIRE-3D.

Accomplishment Description: As shown in the figure, TIRE-3D has been used to predict the footprint pressure distribution of the Boeing B-737 main-gear tire. The tire is a 40x14 aircraft tire, and results are shown for the tire inflated to 95 psi and subjected to a static vertical load of 5000 lbf against a flat plate. The cross section of the TIRE-3D model is shown on the left. For this application the tire is modeled with a combination of laminated shell and 3-d brick finite elements. A color contour plot of the predicted pressure distribution for this tire is shown on the right. The dashed outline of the measured footprint shape for these loading conditions is superimposed on the contour. The contour plot indicates that the peak pressures occur near the outer edge of the tread grooves (the white bands in the contour plot) rather than in the middle of the contact zone. The magnitude of the peak pressure is nearly three times that of the inflation pressure. The shape and size of the computed contact area is in close agreement with the measured footprint shape.

Significance: The verification studies currently underway in the tire industry should build confidence in the analysis procedures and promote the use of the code. The TIRE-3D code will allow tire manufacturers to streamline the tire design process to meet the design challenges associated with such future applications as the National Aerospace Plane and the High Speed Civil Transport. The analysis capability built into the code should provide insights into the underlying physical phenomena associated with the nonlinear structural response of tires to their loading environment.

Future Plans: The current NTMP activity involves the enhancement of the TIRE-3D code to handle thermo-mechanical interactions so that tire carcass temperatures associated with taxi, braking, and steering operations can be accurately calculated. This is an important upgrade since excessive temperature is the chief cause of aircraft tire failures. These enhancements will be completed early in FY 92.

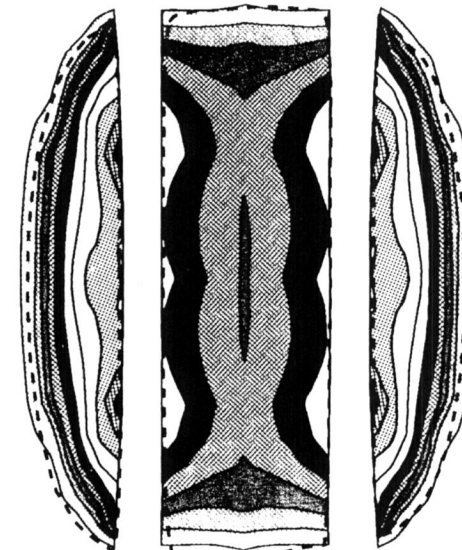
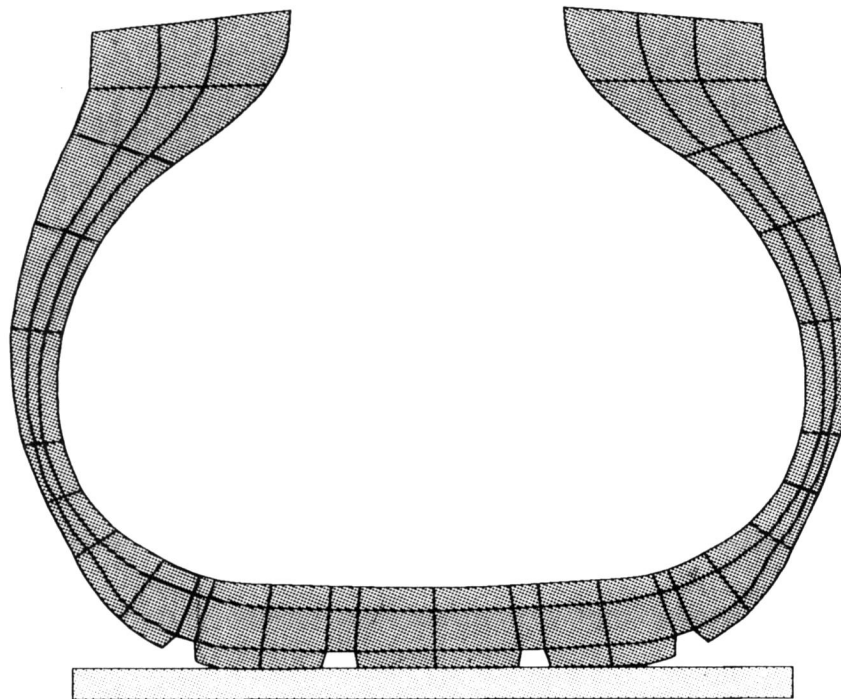
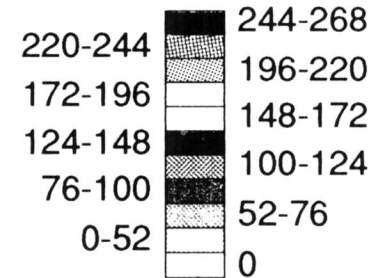
Figure 53 (a).

NATIONAL TIRE MODELING CODE (TIRE-3D) DISTRIBUTED TO INDUSTRY

B-737 MAIN-GEAR TIRE

40 x 14 AIRCRAFT TIRE
INFLATION PRESSURE = 95 psi
CONTACT LOAD = 5000 lbf

PREDICTED CONTACT
PRESSURE DISTRIBUTION, psi



MEASURED
FOOTPRINT
SHAPE

Figure 53 (b).

ACCURATE SENSITIVITY DERIVATIVES FOR SHUTTLE NOSE-GEAR TIRE OBTAINED BY REDUCED BASIS TECHNIQUE

Ahmed K. Noor and Jeanne M. Peters, Center for Computational Structures Technology,
University of Virginia

John A. Tanner and Martha P. Robinson, Landing and Impact Dynamics Branch

RTOP 505-63-10

Research Objective: The objective of this research is to develop a procedure for the efficient calculation of the sensitivity derivatives of the nonlinear response of aircraft tires to variations in tire material and geometric parameters.

Approach: A reduced basis technique and computational procedure has been developed for evaluating the analytic sensitivity derivatives of tire response. The path derivatives of the response vector (with respect to the load parameter) are combined with their derivatives with respect to tire design parameters to approximate the sensitivity derivatives. This computational procedure was applied to the Space Shuttle nose-gear tire subjected to a uniform inflation pressure.

Accomplishment Description: The Space Shuttle nose-gear tire is modeled by using a two-dimensional laminated, anisotropic shell theory with the effects of variation in material and geometric parameters included. The tire carcass is composed of ten plies of rubber and nylon cords and covered with an inner liner and a natural rubber sidewall and tread outer layer. The carcass plies are constructed with nylon cords of two different diameters. The two inner plies contain the smaller diameter cords, denoted by d_1 , and the remaining plies contain the larger diameter cords, denoted by d_2 . The basis vectors were evaluated at a small value of inflation pressure (viz, $p_o/6$) and used in generating both the nonlinear response and the sensitivity derivatives associated with the range of inflation pressure values from $p_o/6$ to p_o . The figure also gives an indication of the accuracy of the transverse displacement at $\xi = 0$, w_c and strain energy U as well as their sensitivity derivatives with respect to the tire cord diameter d_1 obtained by the reduced basis technique. The high accuracy of the response and sensitivity derivative predictions from the reduced basis technique when compared with the full-system computations is clearly demonstrated in the figure.

Significance: The development of analytic sensitivity derivatives of tire response with respect to tire material and geometry parameters will provide the tire industry with powerful analytical tools for tire design and analyses. These derivatives will eventually provide the framework for tire optimization studies that have the potential to significantly enhance the tire design process. The ability to obtain these sensitivity derivatives from the reduced basis technique greatly increases their cost effectiveness as tire analysis and design tools.

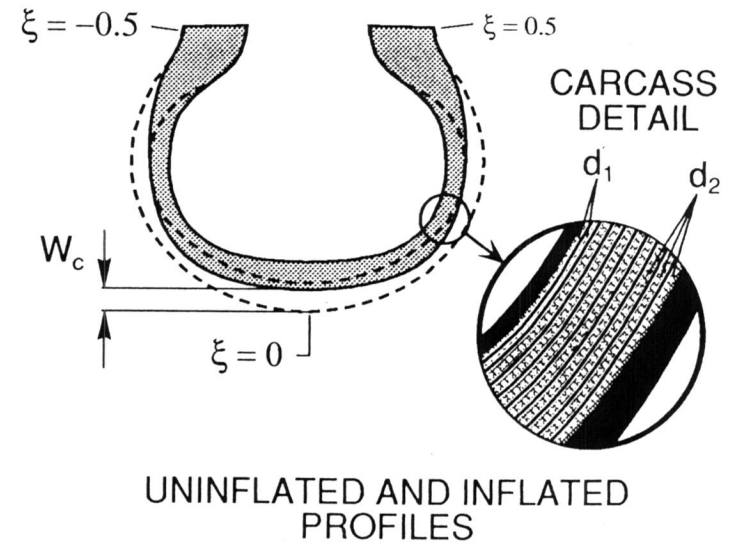
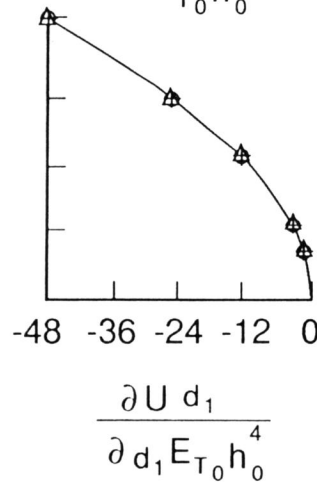
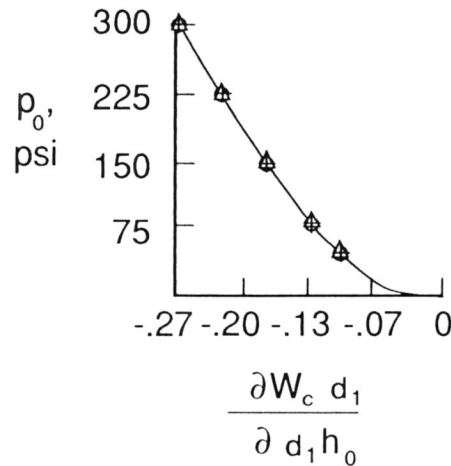
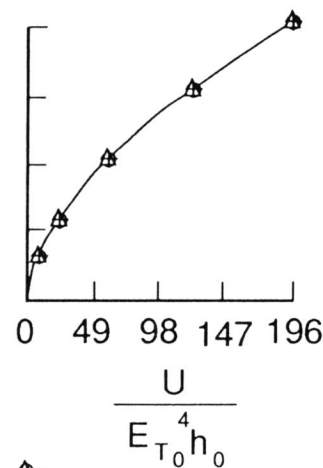
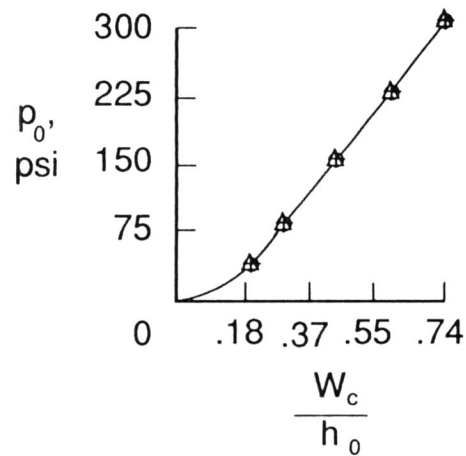
Future Plans: Future activities in tire modeling will apply this computational procedure to more complex tire loading problems such as static contact and rolling contact with braking and cornering forces applied. The reduced basis technique is also being used to obtain the second order sensitivity derivatives so that a wide range of numerical optimization procedures can be used in the tire design process.

Figure 54 (a).

ACCURATE SENSITIVITY DERIVATIVES FOR SHUTTLE NOSE-GEAR TIRE OBTAINED BY REDUCED BASIS TECHNIQUE

$$p_0 = 300 \text{ psi}; E_{T_0} = 1160.3 \text{ psi}; h_0 = 0.75 \text{ in.}$$

135



—	Full System
Basis Vectors	
+	12
○	8
△	4

Figure 54 (b).

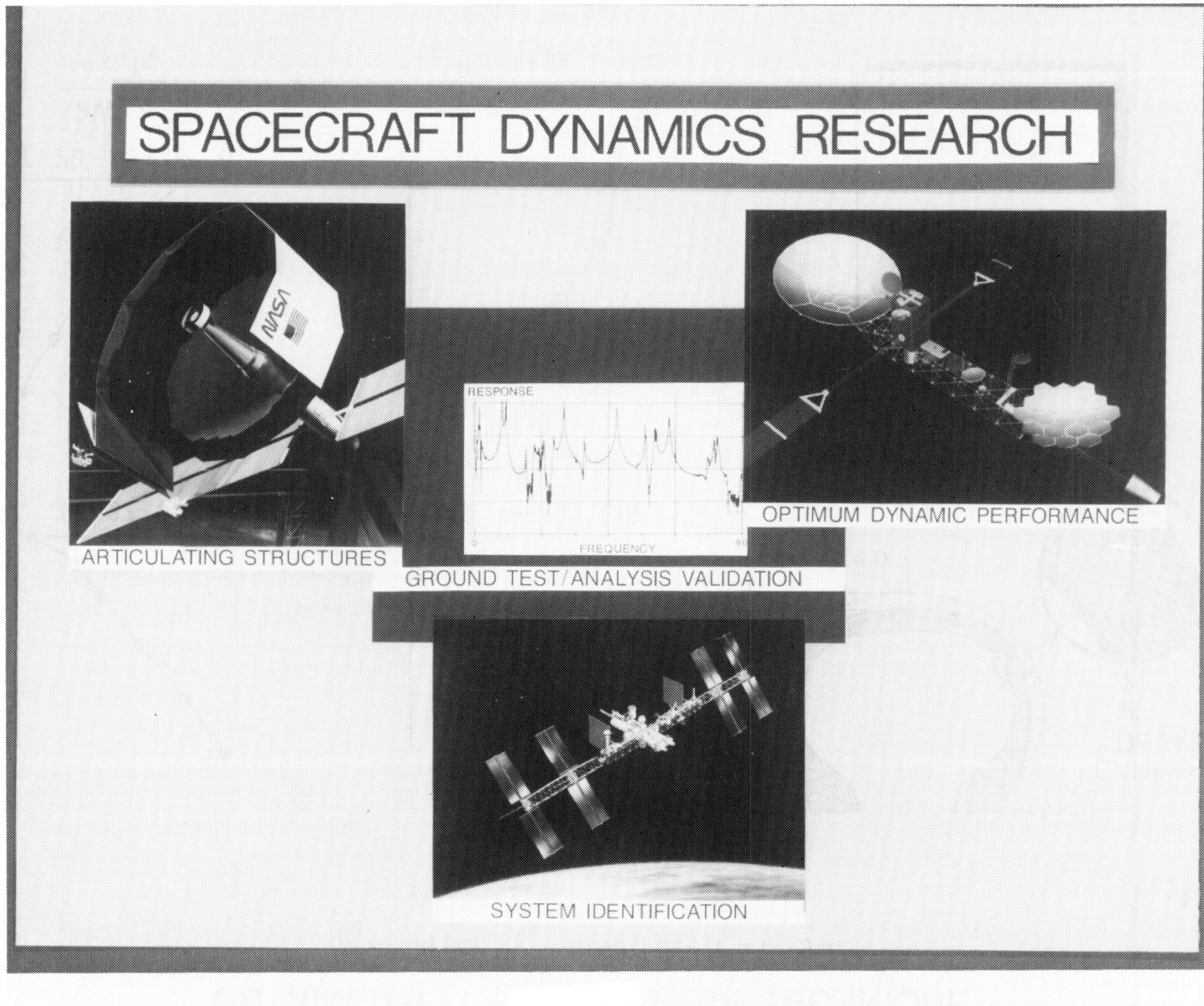


Figure 55.

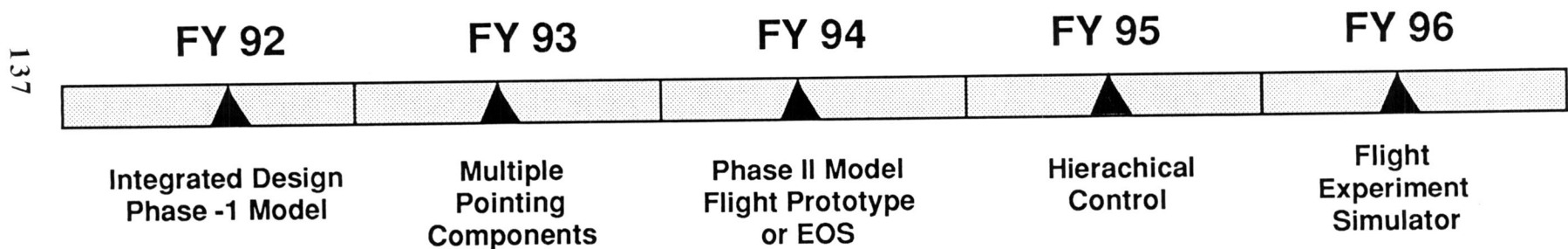
SPACECRAFT DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

DEVELOP CSI GROUND TEST TECHNOLOGY

KEY OBJECTIVES

- IDENTIFY TECHNOLOGY ISSUES USING GROUND BASED TESTBEDS



- VALIDATE CONTROL METHODS FOR FLEXIBLE SPACECRAFT

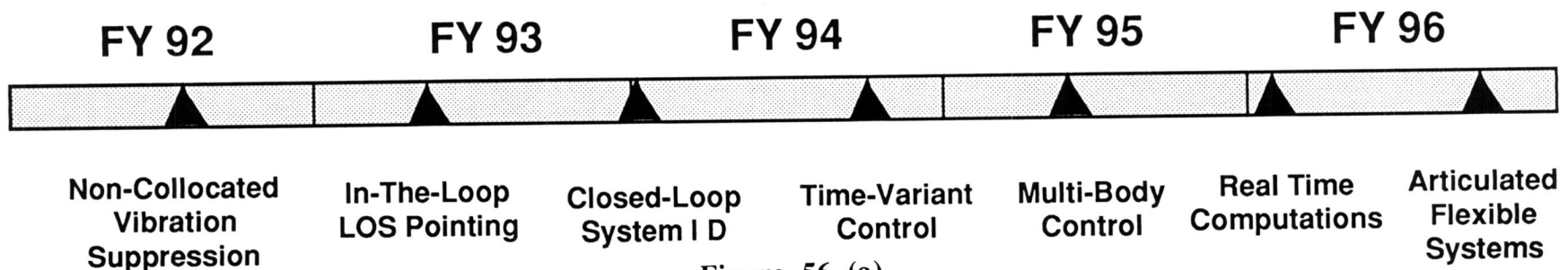


Figure 56 (a).

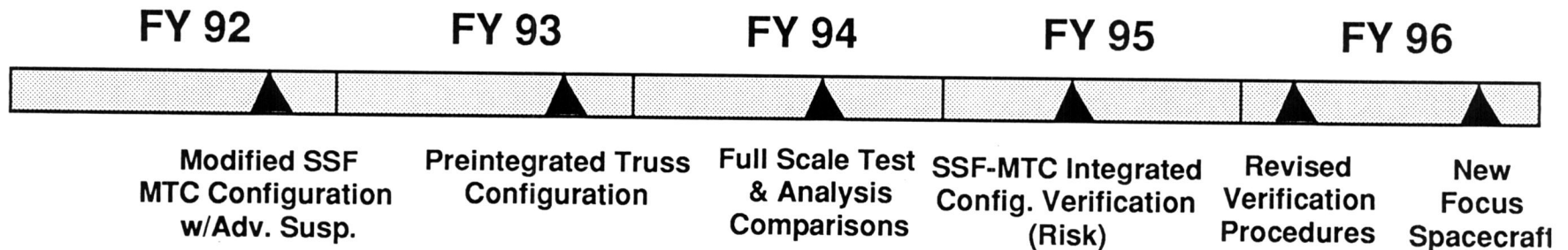
SPACECRAFT DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

DEVELOP VALIDATED TECHNOLOGY FOR PREDICTION OF ON-ORBIT
STRUCTURAL DYNAMICS OF FUTURE SPACECRAFT MISSIONS

KEY OBJECTIVES

● SPACECRAFT GROUND VERIFICATION METHODS VIA SCALE-MODELS



● FLEXIBLE SPACECRAFT ON-ORBIT VERIFICATION METHODS

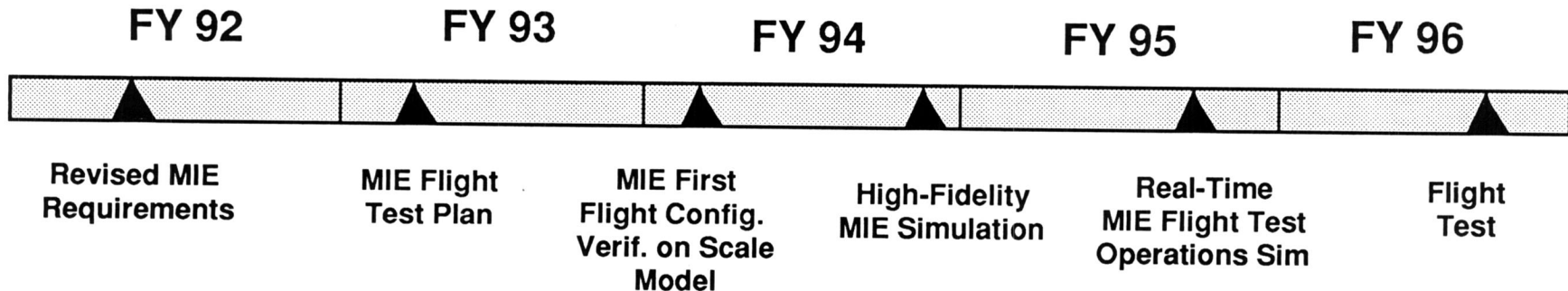


Figure 56 (b).

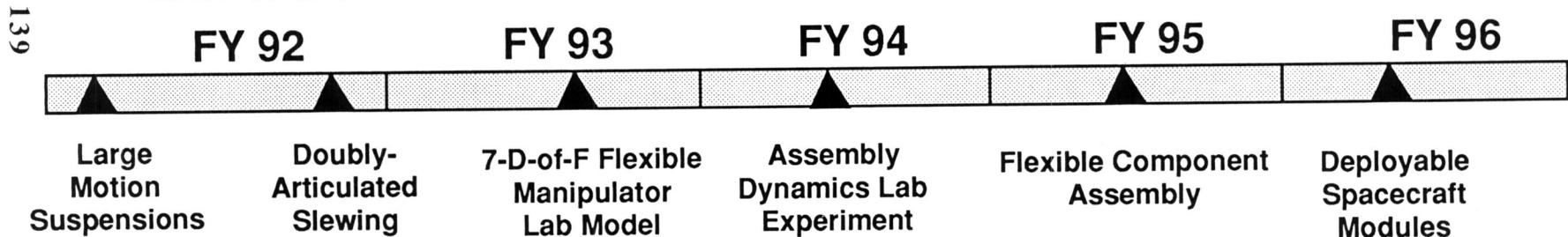
SPACECRAFT DYNAMICS FUTURE PLANS (FY 92-96)

GOAL

DEVELOP ADVANCED METHODS FOR IDENTIFICATION, ANALYSIS,
AND CONTROL OF COMPLEX FLEXIBLE SPACECRAFT DYNAMICS

KEY OBJECTIVES

● MULTI-BODY AND ARTICULATED SYSTEM ANALYSIS & CONTROL



● SYSTEM IDENTIFICATION & ANALYSIS METHODS

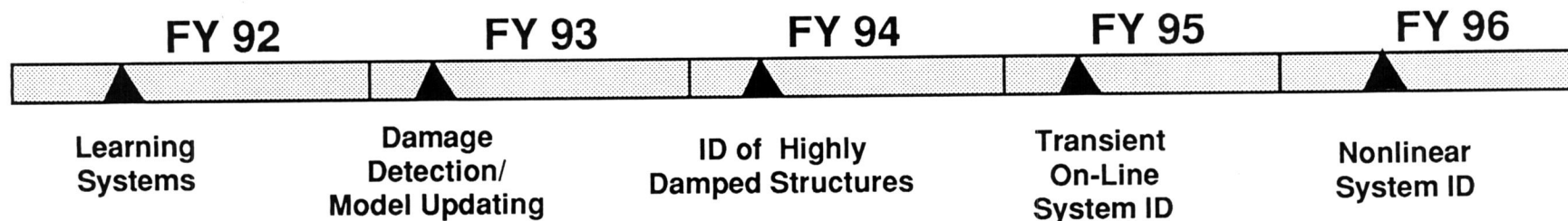


Figure 56 (c).

PHASE-ZERO CSI EVOLUTIONARY MODEL TESTS COMPLETE

W. Keith Belvin, Lucas G. Horta, and Kenny B. Elliott (Spacecraft Controls Branch)

RTOP 590-14-61

Objective: To validate advanced control technology for spacecraft application, a testbed referred to as the Phase-Zero CSI Evolutionary Model (CEM) was developed. Objectives for the CEM testbed include testing various control laws to assess state-of-the-art in the control of flexible spacecraft.

Approach: The CEM testbed is a ground test article consisting of an aluminum truss and several appendages as shown in the attached figure. The structure was designed to possess dynamic behavior similar to geostationary science platforms used for remote sensing. Researchers from NASA and Industry were invited to use the testbed to validate their controller design methodology. In addition, test methods and facilities were developed to support the research objectives. The current research required development of real-time computer systems for implementation of the controllers, calibration and modeling of actuators and sensors, and design and fabrication of the structural test article.

Accomplishment: The CEM testbed has been used to study, low-authority (dissipative) controllers and high-authority (model-based) controllers. Guest investigators from Harris Corporation, Martin Marietta Corporation, the Jet Propulsion Laboratory, IaBG of Germany and two teams from NASA LaRC have been working on various aspects of design, control and system identification of the CEM. Since force actuators (air thrusters and piezo struts) were used to implement the control forces and accelerometers were used to sense the CEM vibrations, dynamic compensators were required to augment the "damping" of the CEM. Dissipative controllers used collocated thruster and accelerometer pairs to produce a highly stable feedback configuration. These dissipative controllers produced significant damping, however, the energy requirements of the dissipative controller were somewhat higher than model-based controllers which use non-collocated sensors and actuators. It was found that the model-based controllers, designed using LQG and H-infinity techniques, often produced an unstable closed-loop system due to differences in the analytic models and the experimental hardware. Usually the low frequency modes, which were most accurately predicted by the analysis models, were stable and higher frequency modes became unstable. To achieve good stability margins and high controller energy efficiency, a combination of model-based and dissipative controllers were implemented in parallel. The resulting high authority, low authority (HAC/LAC) controllers performed very well in damping the CEM vibrations.

Significance: The study of model-based and dissipative controllers has led to a design methodology of using the model-based controller for low frequency modes, which are most accurately predicted by the analytical model, and using dissipative controllers for the higher frequency vibration modes. This combination of controllers has proved to be energy efficient and highly stable. The testbed has also been instrumental in bringing theoretical control design methodologies together with practical hardware to advance spacecraft pointing control technology.

Future Plans: The CEM will be redesigned based on integrated structures and control design methods to improve the controller energy efficiency without increasing the system mass. This new model, the Phase-One version of the CEM, will then undergo a series of tests to validate the integrated design technology.

Figure 57 (a).

THE PHASE-ZERO EVOLUTIONARY MODEL: A CONTROLS-STRUCTURES INTERACTION TESTBED

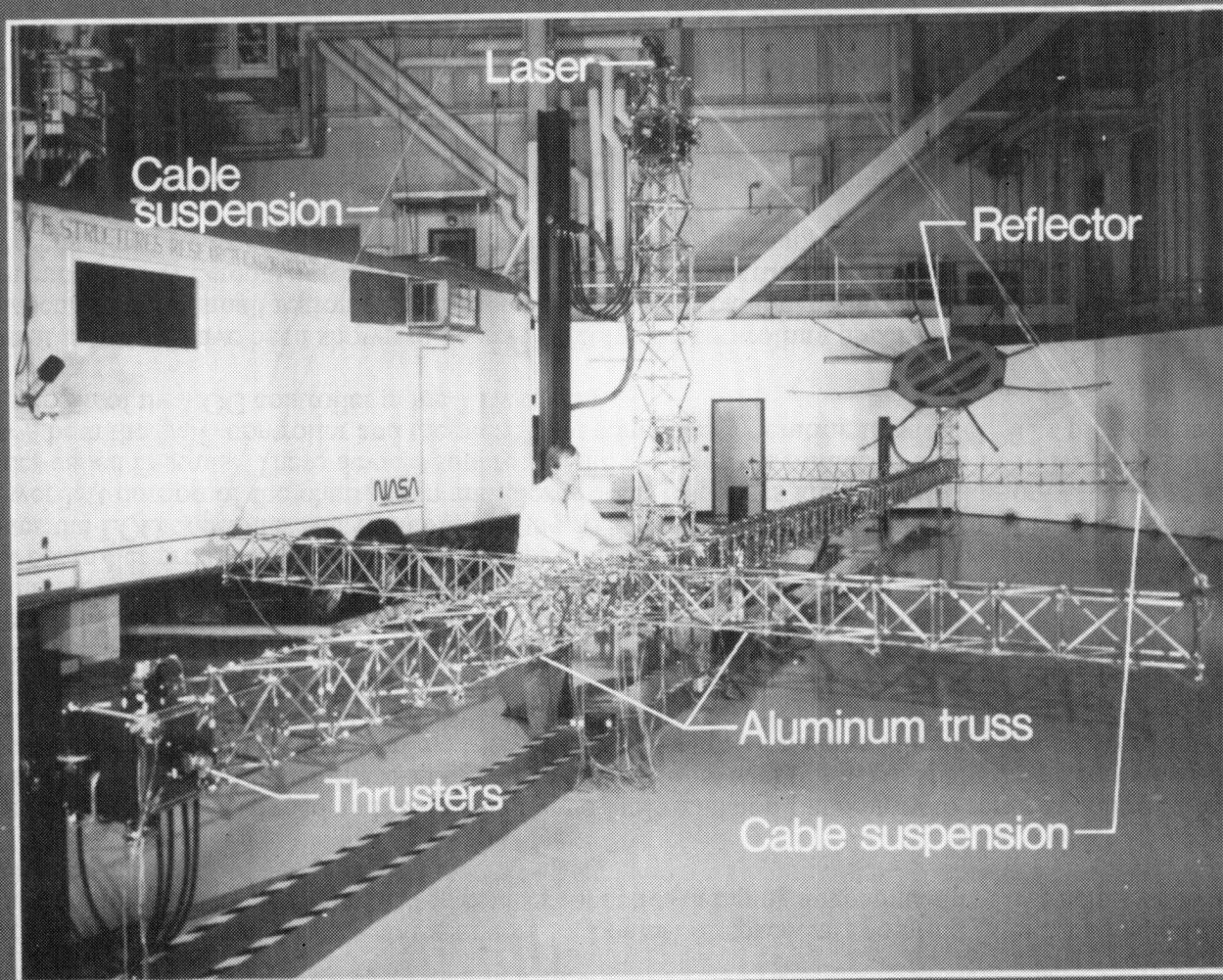


Figure 57 (b).

JPL-LARC PIEZO CEM STRUT TESTS

W. Keith Belvin, Jeff Sulla (LESC), John Won (LESC), Greg Neat (JPL), John O'Brien (JPL), and Boris Lurie (JPL)

RTOP 590-14-61

Objective: The development of advanced sensors and actuators for control of spacecraft pointing jitter must include experimental verification. This research applied piezo-electric actuation devices for active damping augmentation of a structure shown in the upper left portion of the attached chart.

Approach: Truss strut members were designed and fabricated by the Jet Propulsion Laboratory to serve as control effectors in truss structures. The piezo struts were placed on the Phase-Zero CSI Evolutionary Model (CEM) to study the performance of active truss struts in the vibration suppression of flexible vibration modes. Viscous dampers for passive vibration control were also evaluated on the CEM.

Accomplishment: The piezo struts were strategically placed in the base of the vertical CEM appendage to minimize the static preload on the members while providing high control authority of troublesome appendage vibrations. In the upper right portion of the chart, open-loop and closed-loop frequency response curves are shown using a model based controller based on LQG design techniques. The LQG controller produced larger vibration amplitudes in a vibration mode at 7 Hz than occurred in the open-loop response. This indicates the LQG controller was destabilizing the 7 Hz mode which corresponds to a bending mode of the vertical appendage. In the lower left portion of the chart, open and closed-loop responses are shown using only the piezo struts and the passive damping devices called D-struts. These devices suppressed the vibration magnitude in the 5 to 10 Hz bandwidth. The figure in the lower right shows both the LQG controller and the piezo strut controllers operating in parallel. The piezo struts substantially improved the stability margin of the LQG controller in the 7 Hz region.

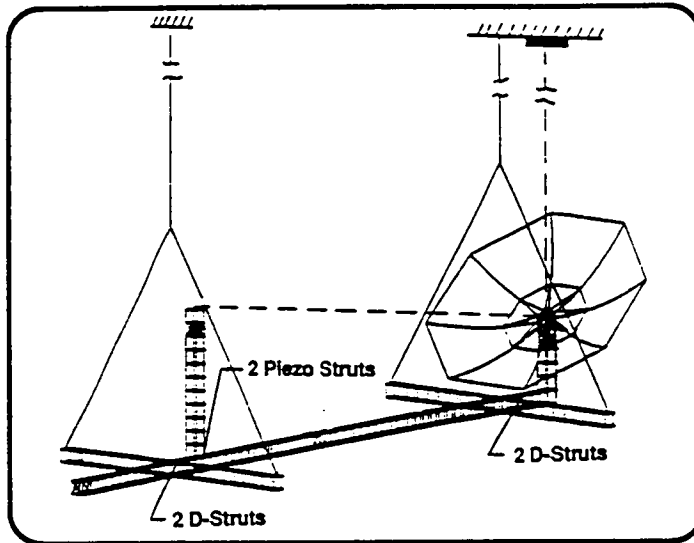
Significance: Piezo strut actuators have been shown to be very effective in controlling appendage modes where a large portion of the strain energy is concentrated in a small region of the structure. The use of parallel controllers for both global and local vibration mode control has been successfully demonstrated. The simplicity of the piezo strut controllers which can operate using only local sensor data indicates decentralized controllers are quite practical for spacecraft jitter suppression.

Future Plans: The piezo struts will be redesigned to permit higher static load carrying capability. Investigations will then proceed to evaluate piezo strut actuators for control of both local and global vibration modes. Studies will be undertaken to determine the number and optimal placement of active struts in the CEM.

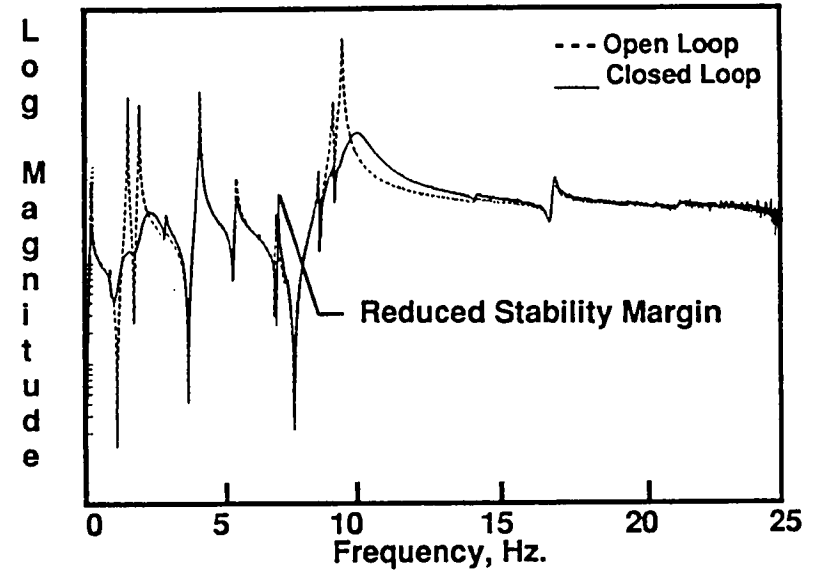
Figure 58 (a).

JPL-LaRC CEM Piezo Strut Tests

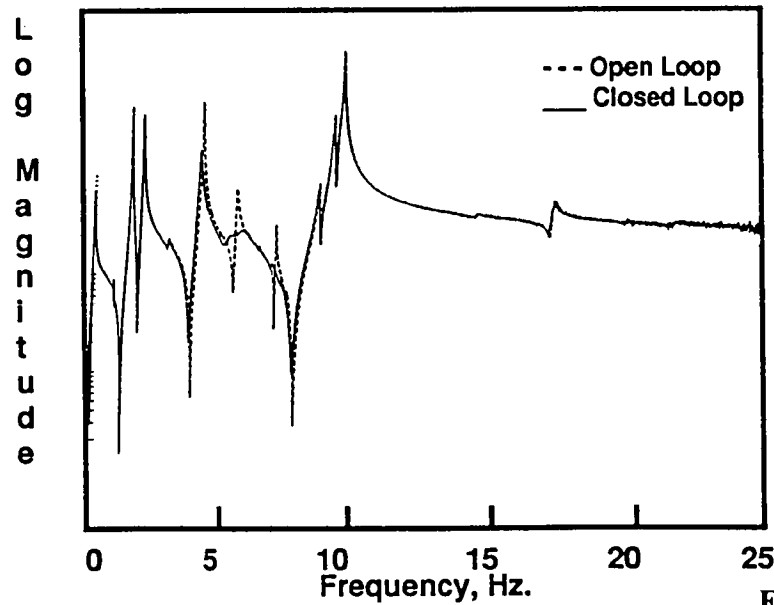
CEM Testbed Configuration



LaRC HAC/LAC Controller



JPL Piezo and D-Strut Control



Combined JPL-LaRC Controllers

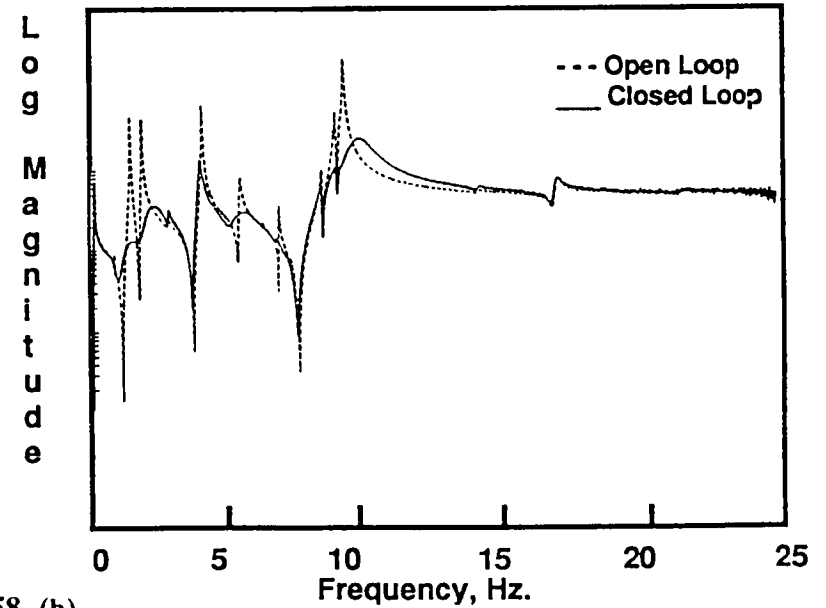


Figure 58 (b).

CSI COMPUTER SYSTEM (CCS)/REMOTE INTERFACE UNIT (RIU) ACCEPTANCE TESTING

Dean W. Sparks, Jr.
Spacecraft Controls Branch

RTOP 590-14-61

Objective: Currently, the computer systems which are used to execute real time control tests on large structure ground experimental articles are not spaceflight qualified systems. These ground based computer systems do not have to contend with having to be hardened for launch and on-orbit space conditions, and having constraints on power use and weight, as would a flight system. It is important to develop spaceflight qualified computer systems, with computational performances as close as possible to ground based systems, in order to perform useful control/structure experiments in space. The objective of this work was to validate the functionality of a proposed flight system, which consisted of: the CSI Computer System (CCS), which included a commercial spaceflight qualified computer programmed in-house; the Remote Interface Unit (RIU), which was a flight like data acquisition and filtering computer designed and built at the Langley Research Center.

Approach: A series of validation tests was conducted on the CCS/RIU system in the Space Structures Research Laboratory (SSRL), including experimental control tests with the CSI Evolutionary Model (CEM) Phase-0 Testbed. First, the flight computer's hardware was checked by following the vendor provided hardware acceptance test procedure. Next, the Langley developed software was verified in terms of configuring the CCS/RIU system for experiments, computing pre-test parameters, computing the programmed control law and recording the test data in real time. Following this, previous CEM open loop excitation and closed loop control tests, executed on ground based computer systems, were repeated on the CCS/RIU. After these tests, several features of the CCS/RIU system were tested individually: automatic and manual experiment safing, RIU digital filtering and RIU standalone tests, where the RIU's onboard DSP executed simple control laws without the CCS being used. Lastly, tests were performed to measure the system's speed in performing closed loop control tests for various controller sizes with a fixed number of sensor inputs and actuator outputs.

Accomplishments: The CCS/RIU system successfully passed the series of validation tests. Both the open loop and closed loop test results executed on this system matched previous results obtained on other ground based computer systems and were repeatable. The two top plots show sample results, comparing a CEM closed loop test with the same controller executed on the CCS/RIU and on a ground based computer system. The system's capability to perform test article safing, RIU digital filtering and standalone execution have also been confirmed. Finally, the computation speed tests have confirmed that the CCS/RIU system could execute closed loop controllers, involving 60 states, with 8 actuator outputs and 8 sensor inputs, at sampling rates in excess of 200 Hz (see bottom figure).

Significance: This work has shown that the CCS/RIU system, a computer system based on spaceflight qualified or near flight like hardware, gives comparable real time performance with ground based computer systems and that meaningful control/structure experiments, conducted in space, could be accomplished using a system such as the CCS/RIU.

Future Plans: The CCS/RIU hardware will be used to verify that various CSI control methods can be implemented in flight-like real-time control computers.

Figure 59 (a).

CSI COMPUTER SYSTEM (CCS)/REMOTE INTERFACE UNIT (RIU) ACCEPTANCE TESTING

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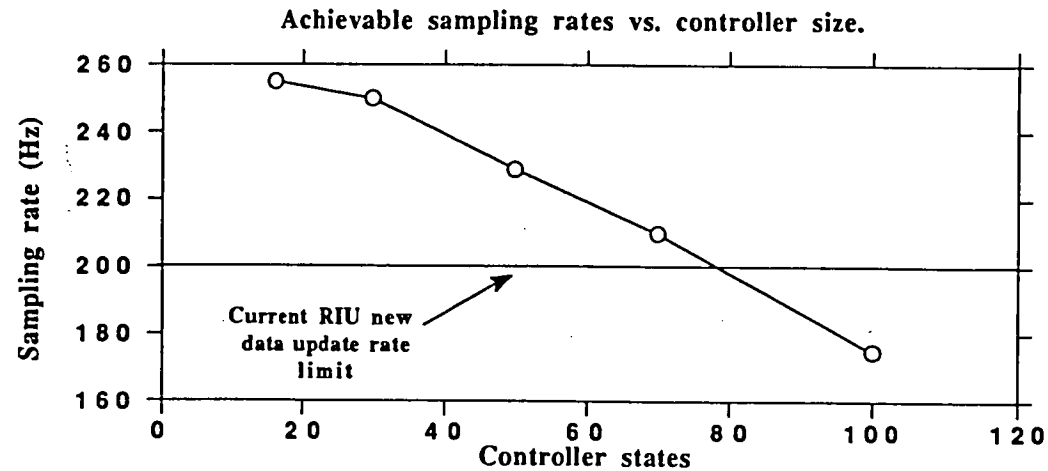
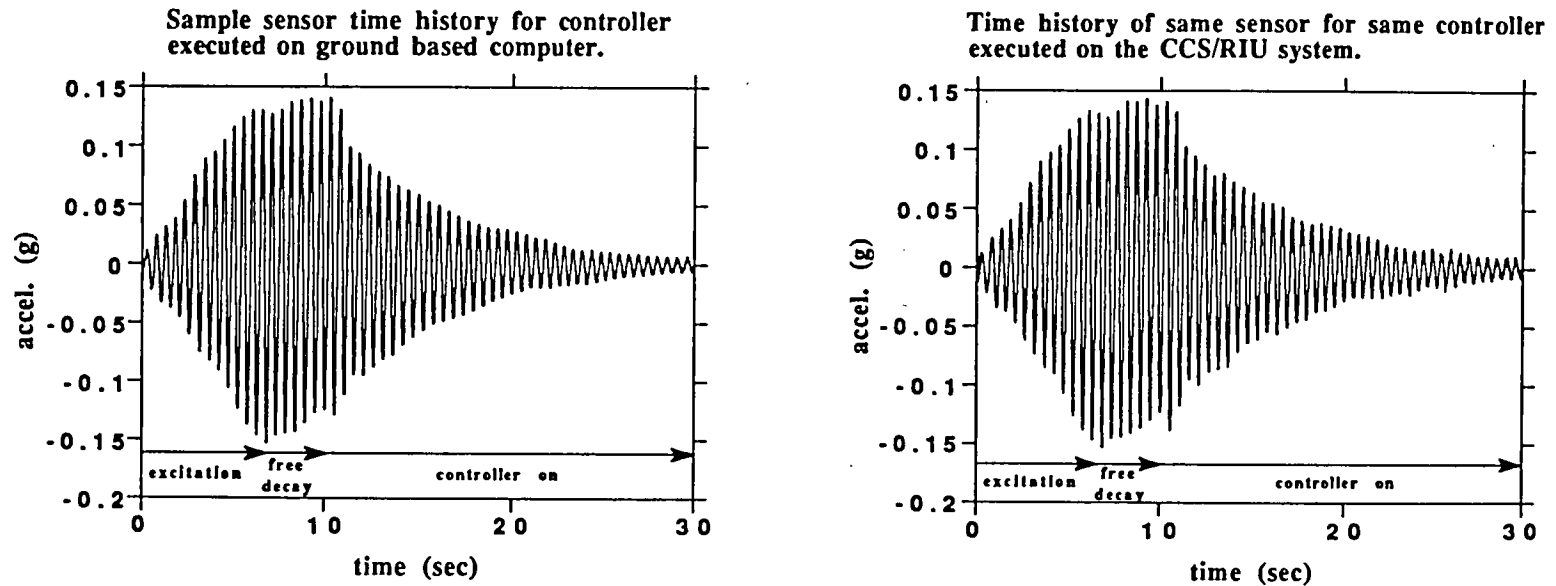


Figure 59 (b).

HUBBLE SPACE TELESCOPE SOLAR ARRAY VIBRATION PARAMETERS IDENTIFIED FROM FLIGHT DATA

Jer-Nan Juang, Lucas G. Horta, W. Keith Belvin and John Sharkey (MSFC)

RTOP 590-14-21

Objective: The objective of the current research is to identify vibration parameters, including frequencies, damping ratio and uncertainty characteristics, of the Hubble Space Telescope (HST) from flight data. The recently developed Observer/Kalman Filter System Identification (OKID) method was used for the identification.

Approach: The HST has six rate gyros to measure angular motions and four torque wheels to provide attitude control moments. The angular rates measured along four of the six gyro directions are combined and transformed using least-squares to recover rates in three vehicle rotation coordinates. Command inputs to the HST are given in terms of angular acceleration in the three rotational vehicle coordinates, which are projected on the four torque wheel axes to actually move and point the spacecraft. For system identification purposes, the HST was excited by torque wheel command pulses combined with sine-sweeps for 50 seconds. This excitation signal was repeated six times in each rotational axis of the spacecraft. Rate gyro signals during the excitation period were sampled at 40 Hz. with a measurement resolution of 0.005 arcsec/sec. The top figure shows the first 20 seconds of command signal for the first vehicle coordinate axis. The OKID technique was applied to the rate gyro response data to identify the vibration parameters. The OKID is recently developed by the researchers in the Spacecraft Dynamics Branch.

Accomplishment: A linear model and observer were identified for the Hubble space telescope. Three dominant frequencies and damping ratios were determined. The 0.65 Hz mode is believed to be an in-plane bending mode of the solar array, the 1.29 Hz mode is a coupled solar and membrane mode, and the 2.45 Hz mode is the first mode of the primary deployment mechanism with the solar array housing attached. The identified dampings are higher than expected because there was a closed-loop controller active during the excitation periods. The response of the identified model is shown compared to the measured response with good correlation. Comparison of the observer output with the measured response shows extremely good agreement, indicating that the observer is correcting for the system uncertainties including nonlinearities. Input modifications were recommended to MSFC for future on-orbit data collection. Multiple tests per axis with differing excitation levels are preferred for further characterization of system nonlinearities. For better identification of particular modes, additional excitation forms such as sine-seeps and discrete frequency inputs are needed.

Significance: The identified system model obtained by this method is more accurate than those of other approaches because the unmodeled dynamics and measurement noises are incorporated into a system observer form. A system observer identified from measured response data is available for direct use in observer-based control law designs. Also, the identified observer can be used to characterize the unknown system uncertainties and measurement noise which often require considerable engineering insight and judgement.

Future Plans: Work with MSFC and other NASA centers in the further analysis of the existing Hubble flight data will continue. Based on identified model results, other studies will include controller designs for active control of solar array vibration.

Figure 60 (a).

HUBBLE SPACE TELESCOPE SOLAR ARRAY VIBRATION PARAMETERS IDENTIFIED FROM FLIGHT DATA

- Data supplied by MSFC
- LaRC developed Observer / Kalman Filter Identification (OKID) method applied
- Dominant frequencies and damping ratios determined

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Frequency (Hz.)	Damping Ratio (%)
0.65	5.5
1.29	3.5
2.45	6.9

- Recommended input modifications to MSFC for future on-orbit data collection
 - Multiple (3-4) tests per axis with differing excitation levels
 - Additional excitation forms (sine-sweeps, discrete frequencies, etc.)

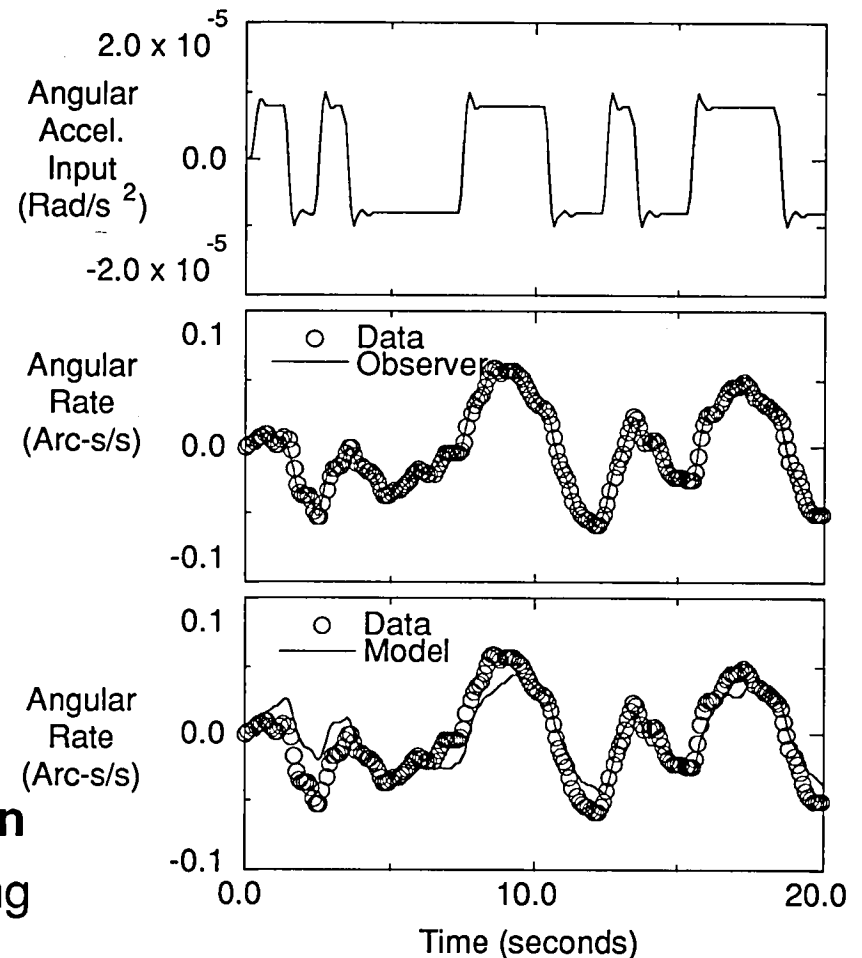


Figure 60 (b).

SPACE SHUTTLE RMS ACTIVE DAMPING AUGMENTATION FEASIBILITY DETERMINED

Michael A. Scott (Spacecraft Controls Branch), Michael G. Gilbert, and Martha E. Demeo (AS&M)

RTOP 590-14-41

Objective: An improvement of spacecraft performance through active control of the structural dynamic response of the vehicle is particularly important for modern spacecraft designs with large size and reduced stiffness. Control-Structure Interaction (CSI) design methods have been developed to predict and improve flexible spacecraft performance, but these methods remain largely unvalidated by hardware demonstrations or actual applications. One potential application of CSI technology is to provide active damping augmentation of the Space Shuttle Remote Manipulator System (RMS), which currently exhibits low damping and long periods of oscillatory motion following most operational maneuvers. The objective of this ongoing study is to determine the feasibility of actively augmenting the damping of the Space Shuttle RMS.

Approach: A nonlinear simulation code (DRS) of the Space Shuttle RMS has been obtained from the Charles Stark Draper Laboratory. Simulated response data from the DRS is used in system identification procedures to derive linear models of the RMS about specific configurations with a representative RMS payload. The linear models are used to design control laws to actively damp the vibratory motions of the RMS. The performance of the control laws is validated using a version of the DRS modified to include closed-loop feedback control of the RMS from joint sensors and hypothetical boom mounted accelerometers.

148 **Accomplishment:** Based on the computed response of the RMS to various inputs, the control laws will need to damp very low frequency motions. Initial single-input, single-output results (see figure) indicate that only a small increase in the level of damping can be achieved with the present sensors on the RMS. Additional feedback sensors in the form of accelerometers located at the tip of the arm can most likely significantly improve the achievable damping, and would probably be required for an actual application. Multiple-input, multiple-output results confirm these conclusions. A potential active damping implementation scheme for the Space Shuttle General Purpose Computer software has also been identified which does not modify any of the current operational procedures or characteristics of the RMS.

Significance: Initial study results indicate that active damping augmentation of the RMS is feasible provided that acceleration feedback is available. Performance benefits include reductions in the decay time of undesired vibratory responses following operational maneuvers and Space Shuttle thruster firings, and also reductions in RMS loads during thruster firings.

Future Plans: More detailed active damping augmentation control law design, implementation, and validation studies are planned using the DRS code. Candidate control laws developed during this study will be tested in realistic operational scenarios using the man-in-the-loop Shuttle Engineering Simulator (SES) at the Johnson Space Center in Houston, Texas.

Figure 61 (a).

SPACE SHUTTLE RMS ACTIVE DAMPING AUGMENTATION FEASIBILITY DETERMINED

- LaRC / JSC "Bridge" program looking at active damping of RMS
- GCD, SDyD, and ISD activity coordinated by CSI Program Office
- Feasibility using existing or minimal additional hardware determined analytically
- Linear models derived from nonlinear RMS simulation data used for feedback gain selection and damping calculations
- Nonlinear simulation code used directly to validate tachometer results
- Results justify man-in-the-loop simulation at JSC on the Shuttle Engineering Simulator

Predicted Damping Changes
From Tachometer and
Accelerometer Feedback

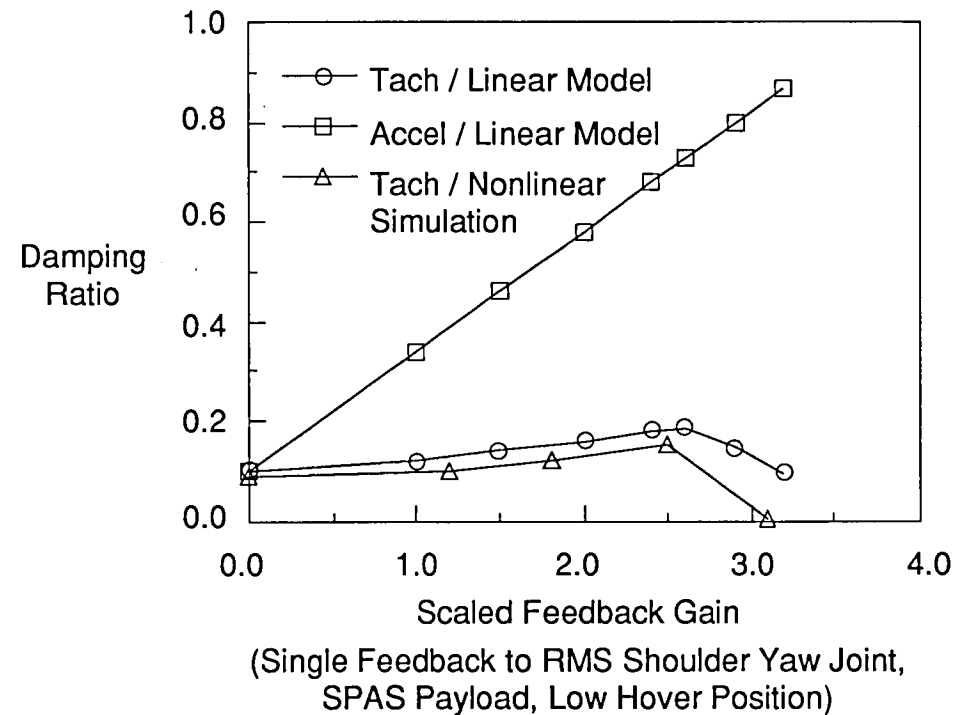


Figure 61(b).

DSMT ANALYSIS MODEL UPDATED VIA INCLUSION OF TEST VERIFIED COMPONENT MODELS

Mehzad Javeed (LESC), Harold H. Edighoffer (AS&M) and Paul E. McGowan

RTOP 590-14-31

Objective: To validate procedures for updating system structural dynamics models based on inclusion of test verified component models.

Approach: To obtain a verified finite element model (FEM) of the DSMT HMB-2 hardware, various components of the hardware were identified for individual testing. These components include bays of truss, rotary alpha and beta joints, various pallets, and rigid and flexible versions of solar arrays and radiators. Static and dynamic tests of each component with carefully selected boundary conditions were performed to accurately determine structural dynamic characteristics (frequencies and mode shapes). The FEM of each component was appropriately modified based on the results of the test-data analysis, and the the updated component FEM's were incorporated into the full system FEM model.

Accomplishment: Static and dynamic test of 6 components have been completed. The finite element model of these components have been updated based on the results of test-data analysis. These components are an eight bay truss section inboard of the alpha-joint, a two-bay truss section outboard of alpha-joint, a rigid EPS radiator, a rigid TCS radiator, and two rigid solar arrays. A full system structural dynamic test of the HMB-2 model with rigid appendages has also been completed. A comparison of the original and component updated FEM analysis results with the system test data was conducted. The correlation between the full system test and updated analysis model was improved due to inclusion of the test verified finite element models of the 6 components tested. It is expected that the correlation of the system test and analysis models will improve further once more of the updated finite element models of the remaining components have been included in the system model.

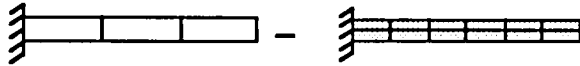
Significance: The trend toward increasing the size and complexity of space structures will reduce the feasibility of verifying the full structural models through ground test methods. More emphasis will be placed on verifying models of segments of the full structure at the component level. One of the objectives of the DSMT program is to identify the issues involved in this approach. Once the component test verified models have been integrated into the system model, by comparison of the full system analytical and test models the feasibility of this approach can be evaluated and important technical issues will be identified. The knowledge gained from the test/analysis verification process in this program will be valuable to large space structure programs such as the Space Station Freedom program.

Future Plans: The remaining components of the HMB-2 model will be tested to determine their static and dynamic structural characteristics. The finite element models of the components will be updated based on the results of the test-data analysis. The updated finite element model of the components will be included in the HMB-2 system model. The flexible appendages will be assembled on the HMB-2 model for full-system test.

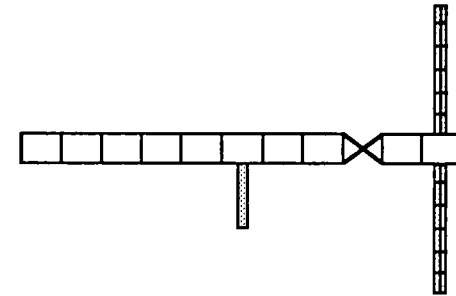
Figure 62 (a).

DSMT ANALYSIS MODEL UPDATED VIA INCLUSION OF TEST VERIFIED COMPONENT MODELS

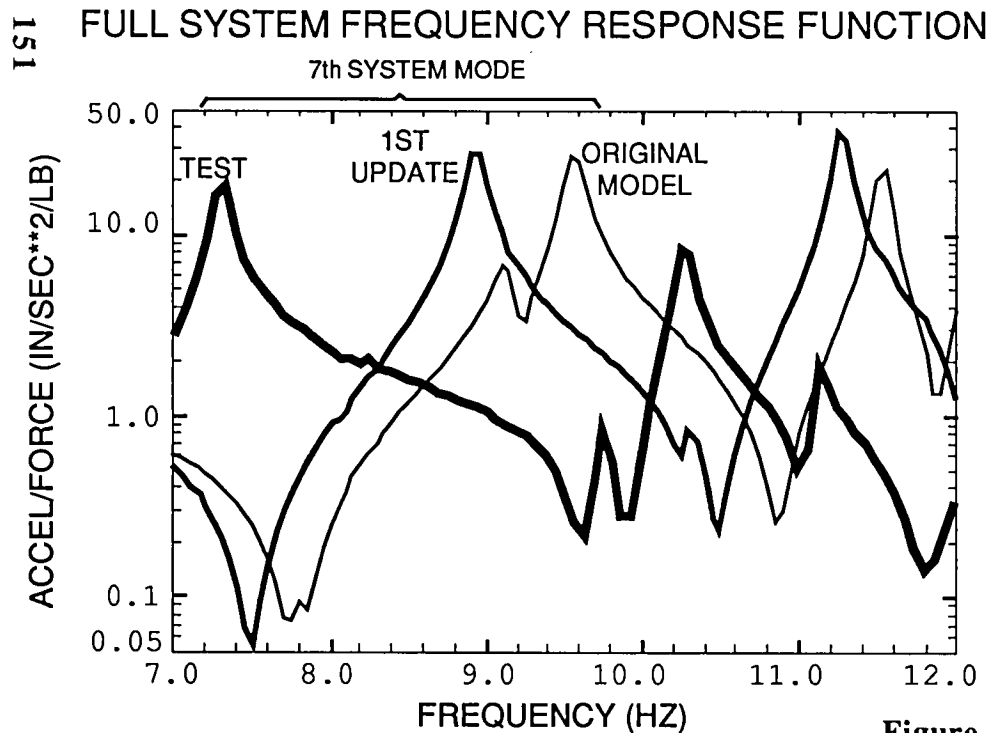
- COMPONENT ANALYSIS MODELS UPDATED BASED ON TEST DATA.



- INCORPORATED TEST VERIFIED COMPONENT MODELS INTO FULL SYSTEM MODEL.



- UPDATED FULL SYSTEM MODEL TEST/ANALYSIS CORRELATION IMPROVED.



HMB-2 FULL SYSTEM MODEL

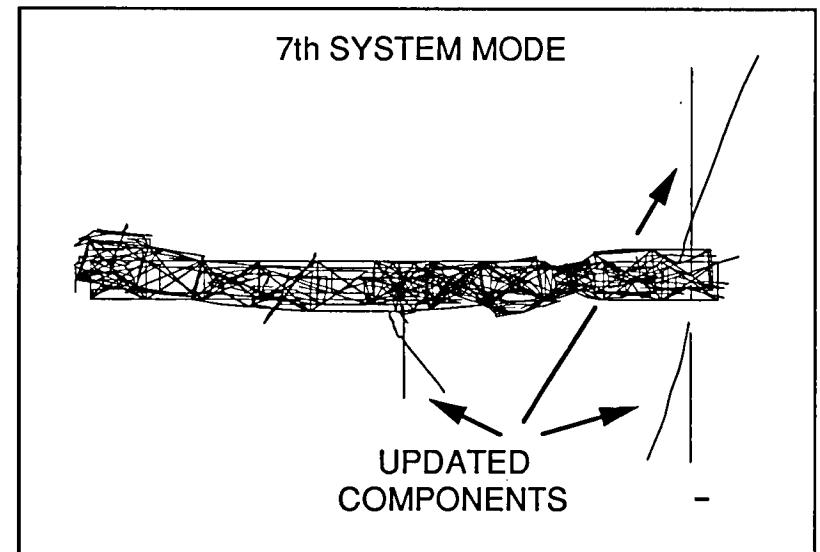


Figure 62 (b).

DYNAMIC PERFORMANCE OF ZERO-SPRING RATE MECHANISM (ZSRM) VALIDATED

Victor Cooley

RTOP 590-14-31

Objective: Low frequency structural models require near-zero constraint boundary conditions for accurate ground testing of modal properties. Bungee cords and/or very soft springs are unacceptable because of long deflection, high energy storage, and creep. The objective of the current research is to validate a Zero Spring-Rate Mechanism (ZSRM) suspension mechanism for application to ground testing of low frequency large space structures such as the Dynamic Scale Model Technology (DSMT) Space Station Freedom model and the Control/Structure Interaction (CSI) evolutionary model.

Approach: The traditional approach for ground test suspension of low frequency structures has been to suspend them using soft springs and/or bungee cords compliant enough so that the rigid body frequencies occur sufficiently (factor of five or more) below those of the flexible body. Such separation ensures that the modes and mode shapes from the two regimes are uncoupled, thus allowing accurate identification of the free-free modal properties. As the frequencies of large spacecraft decrease, the requirement for suspension compliance increases. In the current research a ZSRM suspension device is used to support a spectrum of payload weights from 50 through 400 lbs.

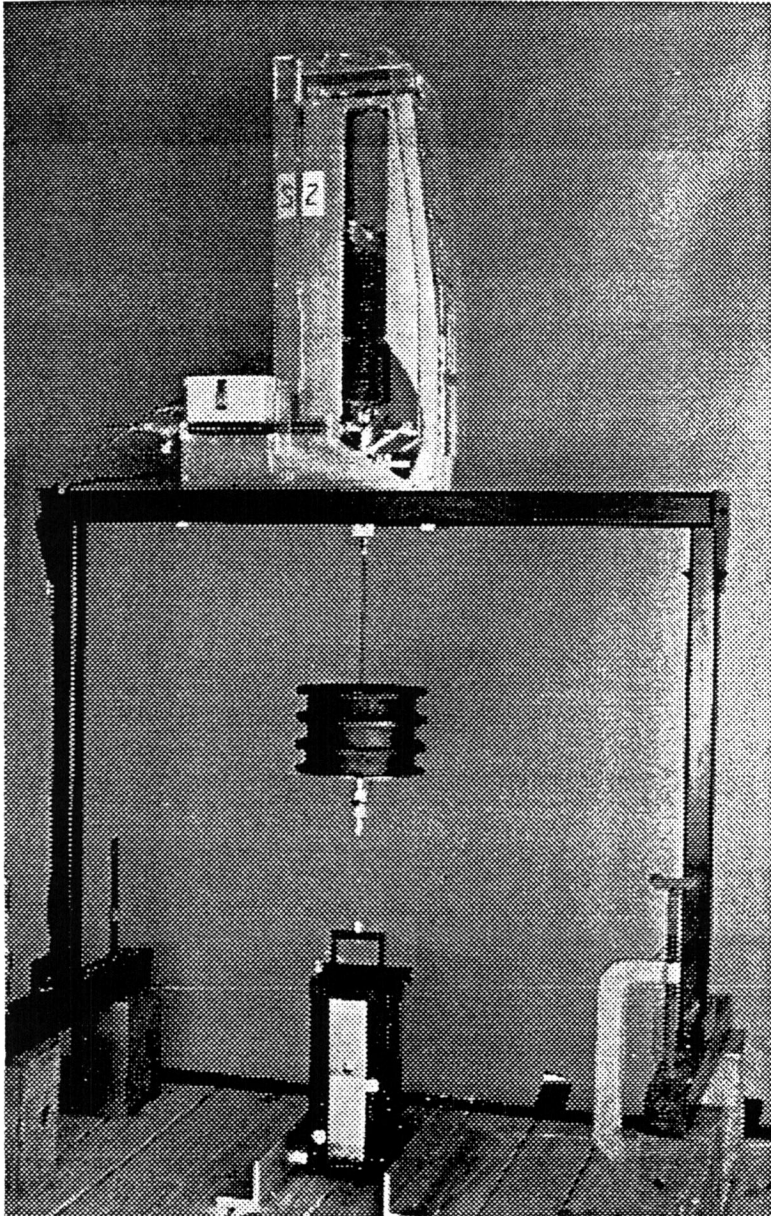
Accomplishment: A series of frequency response tests, using both sine sweep and burst random excitation, was completed to measure the characteristic response of the ZSRM. In the test set-up shown in the figure, a shaker is positioned beneath a 160 lb. rigid payload to provide vertical actuation. A strain gage load cell measures the dynamic force applied to the payload, and, either a noncontacting displacement probe, or an accelerometer measures the system response. The characteristic response formulated from spectra of the two measurements shows a resonant frequency of 0.15 Hz. Testing of payloads throughout the payload design range of 50 to 400 lbs, and at amplitudes up to 0.8 in resulted in resonant frequencies not greater than 0.26 Hz. This testing has validated the ZSRM as a suspension device capable of supporting substantial payloads with a highly compliant and very low frequency constraint.

Significance: Boundary conditions provided by a ZSRM device are more characteristic of free-free boundary conditions than those provided by conventional suspension techniques. The closer the boundary conditions to free-free, the closer are the ground test modal properties to on-orbit modal properties. This improves the ability to correlate analytical free-free models for low frequency modes.

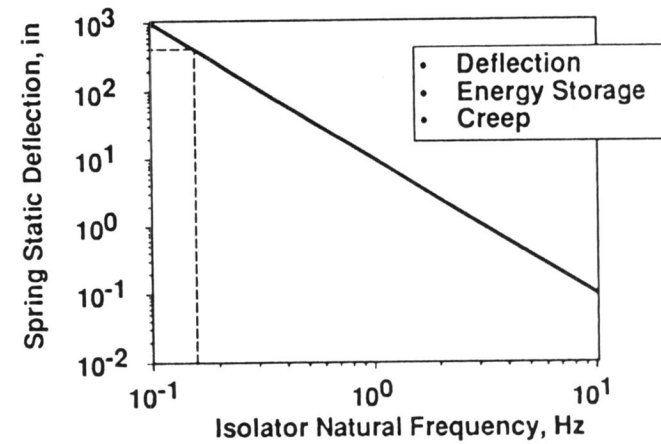
Future Plans: The ZSRM has been tested with rigid payloads and testing with a low frequency flexible, custom designed payload is in progress. Flexible payload testing involves the use of multiple devices supporting one model. Ongoing research is focused on application of the ZSRM's to realistic models in the Spacecraft Dynamics Laboratory.

Figure 63 (a).

DYNAMIC PERFORMANCE OF ZERO SPRING RATE MECHANISM (ZSRM) VALIDATED



Soft Spring Suspension Shortcomings



Test Result

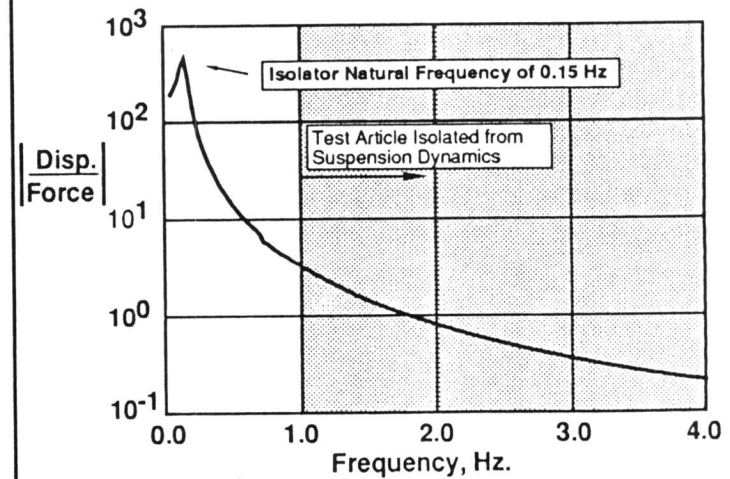


Figure 63 (b).

REFINED FLEXIBLE SOLAR ARRAYS DEVELOPED FOR DSMT MODEL

Kathleen A. Conley, Mehzaad Javeed (LESC) and Paul E. McGowan

RTOP 590-14-31

Objective: To revise the flexible solar arrays for the hybrid-scale space station model used in the Dynamic Scale Model Technology (DSMT) research program to provide dynamic complexity more representative of the full-scale arrays.

Approach: Refined flexible solar arrays were designed and fabricated on contract by Lockheed Missiles and Space Company (LMSC). Each array (shown in accompanying photo) is a flexible mast with two blanket stabilizers that provide bending and torsion coupling similar to the full-scale array. Originally the array consisted of only the flexible mast with lumped masses along the length to account for mass effects. The new array is 11.4 feet long and weighs 13.2 pounds with lumped masses at the ends of the blanket stabilizers to simulate the solar blankets on the full-scale array. The fundamental array frequency, as determined by the hybrid-scaling laws, is five times that of the full-scale array or approximately 0.5 Hz. A design feature also allows the lumped masses to be replaced by a mesh that provides further complexity with membrane modes. The array was made to be compatible with the existing beta-joint design on the DSMT HMB-2F space station model. A finite element model of the solar array component was also developed to be integrated into the complete NASTRAN model of the full system HMB-2F structure.

154 **Accomplishment:** Vibration tests of the new array were conducted at LMSC and at LaRC with the array cantilevered vertically. This configuration was chosen to minimize static deflection during testing and to eliminate the potential for suspension system interactions. A NASTRAN analytical model was correlated with vibration test results such that the first six modes agreed to within a 4 percent frequency error. The effects of differential stiffness due to gravity loading was established, through analysis, to have approximately a 20 percent effect on the first vibration bending modes, but was found to have minor effects on the remaining modes. In order to suspend the arrays horizontally from the gantry, a cable suspension system was designed to alleviate the effects of gravity and to minimize interaction of cable modes with the array modes.

Significance: Interaction between flexible appendages and global structure modes is a significant problem on the space station. In particular, the ground verification of an on-orbit experiment design for the Modal Identification Experiment project depends on an adequate simulation of this effect. The new array design allows investigation into the effects of array bending and torsion coupling, along with in-plane and out-of-plane bending stiffness variation. This is a vast improvement in simulating the full-scale behavior over that provided by the original simple mast (see accompanying figures).

Future Plans: The new solar array hardware will be assembled on the hybrid-scale HMB-2F model for full-system modal testing. Eventually, the lumped masses will be replaced with a mesh simulator to provide even greater modal density in the form of blanket dynamics.

Figure 64 (a).

REFINED FLEXIBLE SOLAR ARRAYS DEVELOPED FOR DSMT MODEL

REFINED SOLAR ARRAY



MODAL DENSITY OF REFINED ARRAYS SIGNIFICANTLY INCREASED

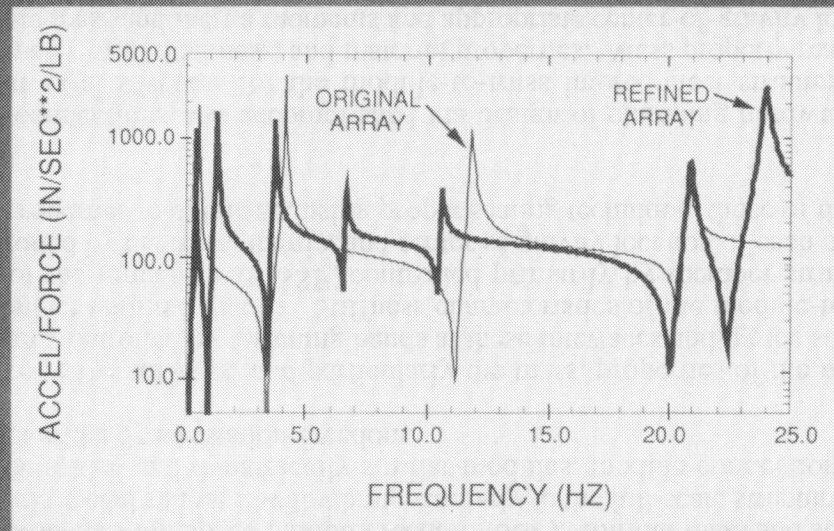


Figure 64 (b).

MODULE CLUSTER ASSEMBLED FOR DSMT HYBRID-SCALE MODEL

Paul E. McGowan and Victor M. Cooley

RTOP 590-14-31

Objective: Dynamic scale models of Large Space Structures (LSS) are used in ground vibration testing to validate scale modeling and testing techniques for large, truss-type, flexible structures such as the Space Station Freedom (SSF). Similar mass and stiffness distributions, to the full-scale structure, are required for the scale model so that it will vibrate similarly to the full-scale structure. The objective of the current hardware development is to produce scaled and dynamically similar modules, module connections, and module-to-truss interconnect structure for a hybrid scale model of the Space Station Freedom.

Approach: The vibration properties of the SSF are sensitive to the stiffness, and particularly the mass, properties of the module cluster. Stiffness properties of module-to-node connections are controlled by fastening bands at these interfaces and by the stiffness characteristics of local structure adjacent to and in direct contact with the bands. Stiffness characteristics of the module-to-truss interconnect structure are, like the truss comprising most of the remainder of SSF, controlled primarily by member strut axial stiffness. The mass properties of the module cluster are controlled by the mass, inertia, and center of gravity location of each module or node. The approach is to design local stiffness and mass properties to duplicate, using proper scaling technique, those of the SSF full-scale hardware.

Accomplishment: Stiffness matching for module-to-node connections was accomplished via design of clamping hardware and structure in the vicinity of the clamps. Matching of strut axial stiffness for the module-to-truss interconnect structure was accomplished using scaling laws with the design of strut diameter, wall thickness, and material properties. Mass property matching was accomplished by designing metal inserts of the appropriate mass and inertia moments and appropriate center-of-gravity location for each of the four main modules. The table below shows the scale model module weights and percent difference from the scaled SSF design weights.

Module	Weight	% Diff.
US Lab	541.0 lbs	-1.16%
US Hab	453.3 lbs	-0.67%
JEM	385.6 lbs	-0.63%
ESA	414.5 lbs	0.86%

Significance: This hardware will provide for accurately scaled mass and stiffness representations of the SSF module cluster, module-to-node connections, and module-to-truss interconnect structure. Connection of the module cluster to remaining SSF scale model will provide a model for development and validation of LSS scale model technology.

Future Plans: The module cluster, or certain partial configurations of the cluster representing intermediate build levels of SSF, will be used in ground vibration testing for development and validation of LSS scale model technology.

Figure 65 (a).

MODULE CLUSTER ASSEMBLED FOR DSMT HYBRID-SCALE MODEL

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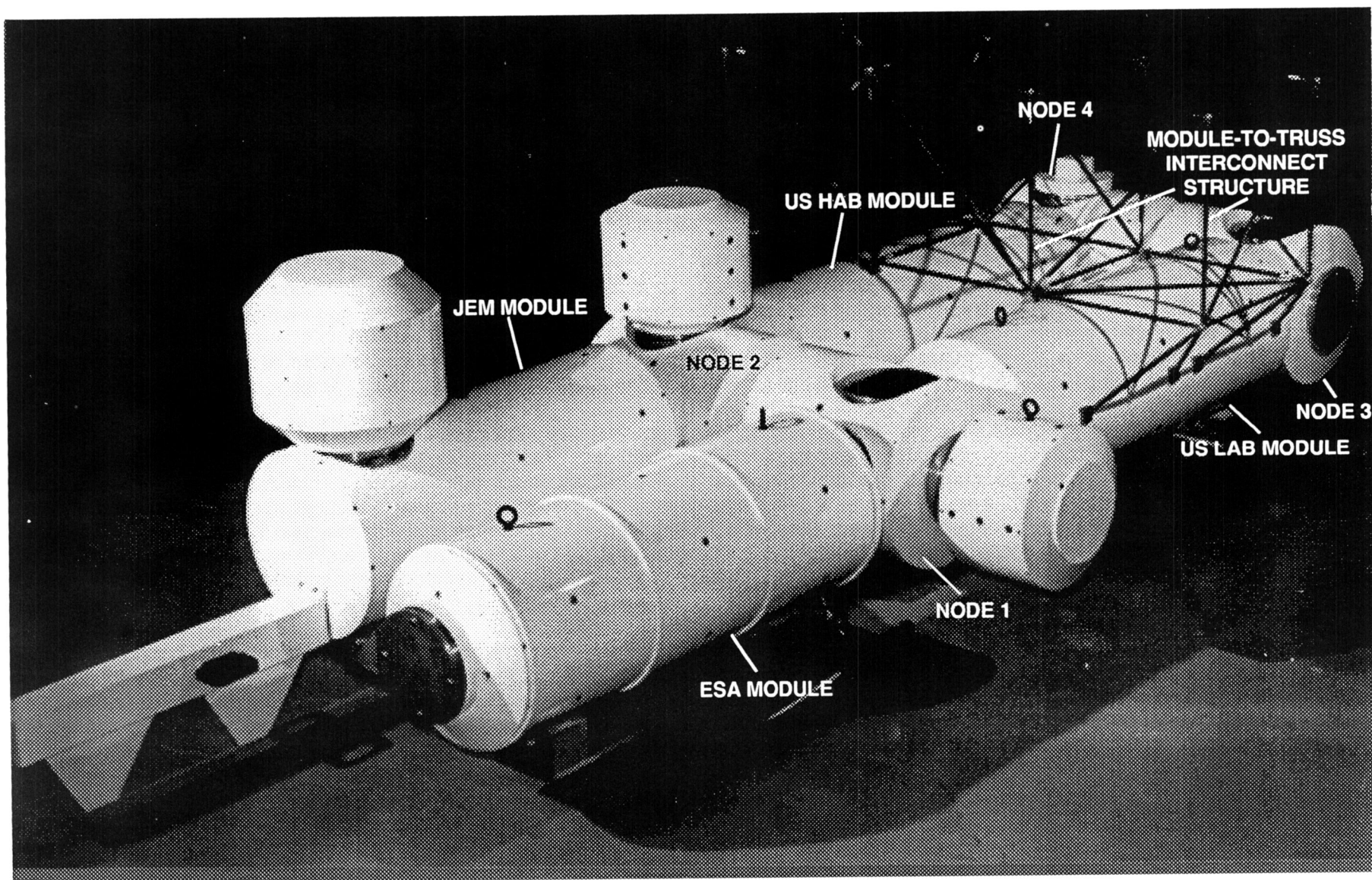


Figure 65 (b).

ROBUST ALPHA-JOINT CONTROLLER DESIGN ACCOMMODATES LARGE STRUCTURAL PARAMETER ESTIMATION ERROR

Renjith R. Kumar (AMA), Paul A. Cooper, and Tae W. Lim (LESC)

RTOP 590-14-31

Objective: The Space Station Freedom (SSF) structure will not be tested as a complete system before being placed on orbit because it cannot support its own weight on earth. Modal frequencies and amplitudes which can be used to describe the dynamic characteristics of the station will have to be predicted using information from component tests and analytical models. The objective of this research is to investigate the tolerance of the Solar Array Alpha Rotary Joint (Alpha-Joint) controller design to possible errors in the predicted modal frequencies and amplitudes.

Approach: SSF will depend on photovoltaic (PV) solar arrays which track the sun during orbital daylight to obtain electric power. Alpha-Joints regulate the relative rotational motion of the outboard structure to the inboard structure (see figure). The PV arrays are attached to the outboard structure. The attitude of the inboard structure is maintained while the Alpha-Joint rotates the outboard structure so that the PV arrays track the sun. A finite element model of the SSF structure was developed for the current study. Then, a robust Alpha-Joint controller was designed for the SSF structural model using an optimization procedure to provide stability robustness to possible structural stiffness and mass changes and to meet transient and steady-state tracking requirements. To investigate how tolerant the Alpha-Joint controller design is to errors in the predicted modal frequencies and amplitudes, the change in stability robustness of the nominal design was evaluated as the modal frequencies and amplitudes were varied (see figure).

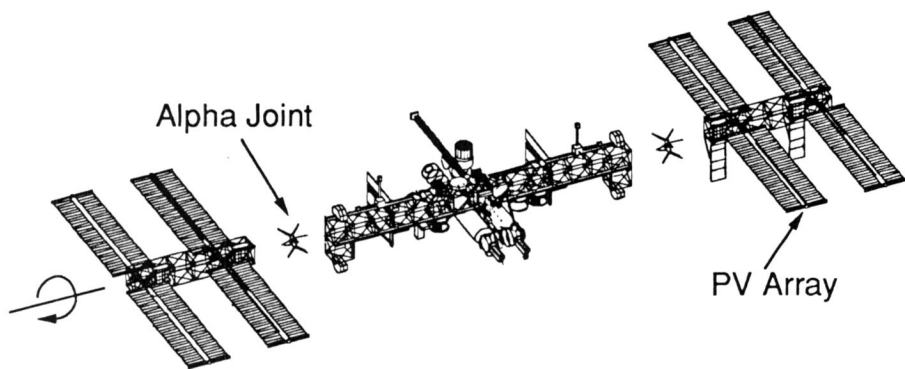
Accomplishment: A procedure of synthesizing the values of the controller design variables was developed using a constrained optimization method. The dominant modes which interacted with the control system were identified and they exhibited PV array bending motion coupled with the rigid-body motion of the outboard truss structure to balance the momentum change (see figure). The nominal design provides enough stability robustness to tolerate a sizable error in predicted frequency (40%) and modal amplitude (200%) of the dominant modes. A conservative modal damping of 0.1% was employed for this study. The high levels of stability margin suggested in this study for the nominal design are prudently conservative.

Significance: The current study shows that accurate knowledge of the structural dynamic characteristics of the SSF structure will benefit the performance of the Alpha-Joint by requiring less stability margin. The quantification of the change in frequencies and mode shapes needed for the control system to lose its stability margin provides useful correlation between the control system stability and the structural parameter accuracy.

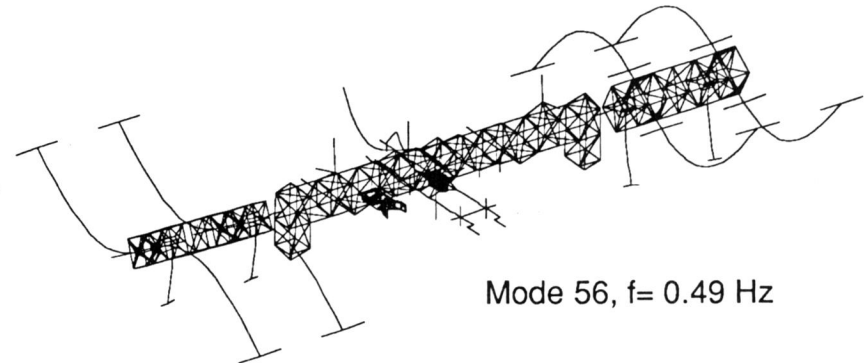
Future Plans: For the current study, it was assumed that the attitude of the inboard structure of SSF was maintained perfectly, i.e., there was no inboard structure attitude fluctuation. The current study will be extended to include the Control Moment Gyro (CMG) controller for the inboard structure. With the CMG's actively employed to control the attitude of the station, the influence of the inboard structure attitude fluctuation upon the Alpha-Joint controller performance will be investigated.

Figure 66 (a).

Robust Alpha-Joint Controller Design Accommodates Large Structural Parameter Estimation Error

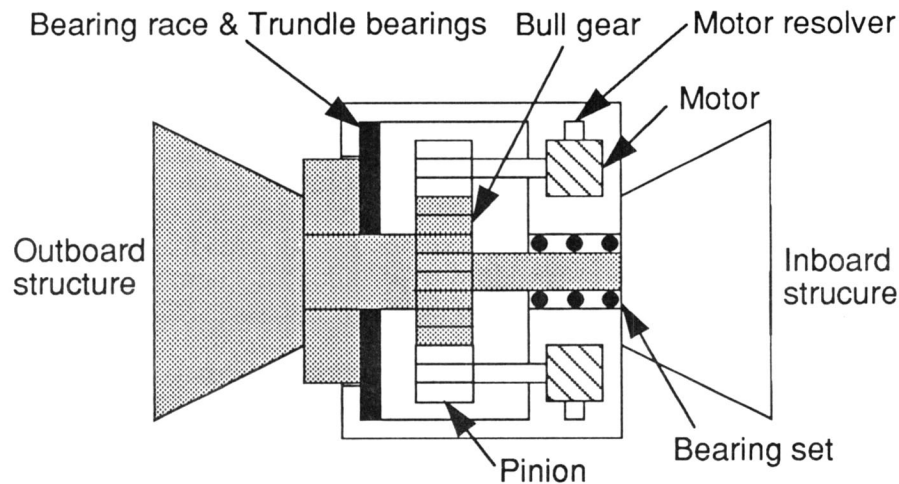


Space Station Freedom

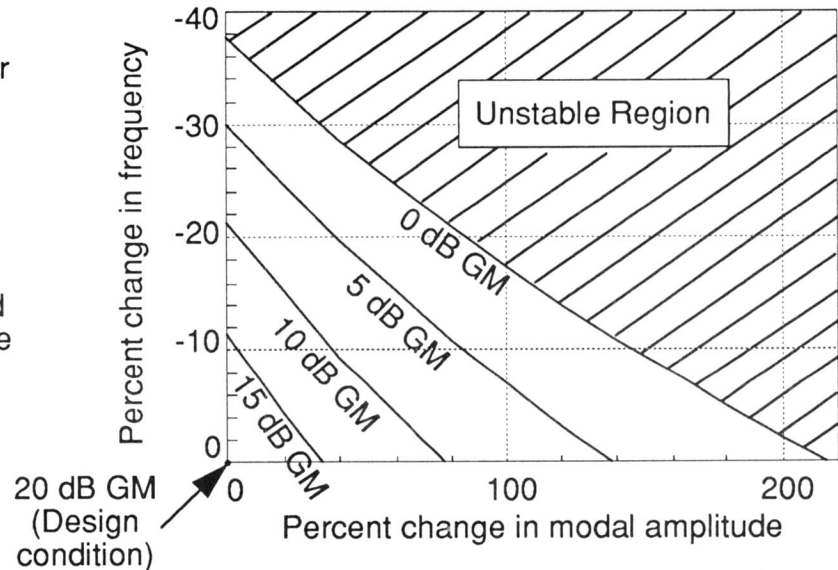


Dominant Structural Mode Interacting with Joint Control

159



Schematic of Alpha Joint Drive Train



Sensitivity of Stability Margin to Variations in Modal Parameters

Figure 66 (b).

MIE SIMULATIONS VALIDATED BY GENERIC MODEL TESTS

Ronald R. Gold (DEI), Mehzaad Javeed (LESC), and Paul E. McGowan

RTR 590-14-31

Objective: To validate procedures for using laboratory scale models to simulate on-orbit excitations of large space structures such as Space Station Freedom.

Approach: Currently, a project entitled the Modal Identification Experiment (MIE) is being proposed as an on-board experiment for Space Station Freedom. MIE proposes to use the station-based thrusters as an excitation source and a limited set of sensors to provide response measurements for determining the station dynamic characteristics. Since no full-scale hardware is yet available for validating the MIE design, the use of dynamically scaled models from the Dynamic Scale Model Technology (DSMT) research project is being explored. Laboratory procedures have been developed for producing scaled excitations simulating the anticipated thruster force levels and types on the scale model. Response measurements are collected in proposed MIE locations to complete the experiment simulation. Modal parameters determined from the on-orbit experiment simulation are compared to those determined from previously conducted ground modal tests to assess the validity of the proposed MIE design.

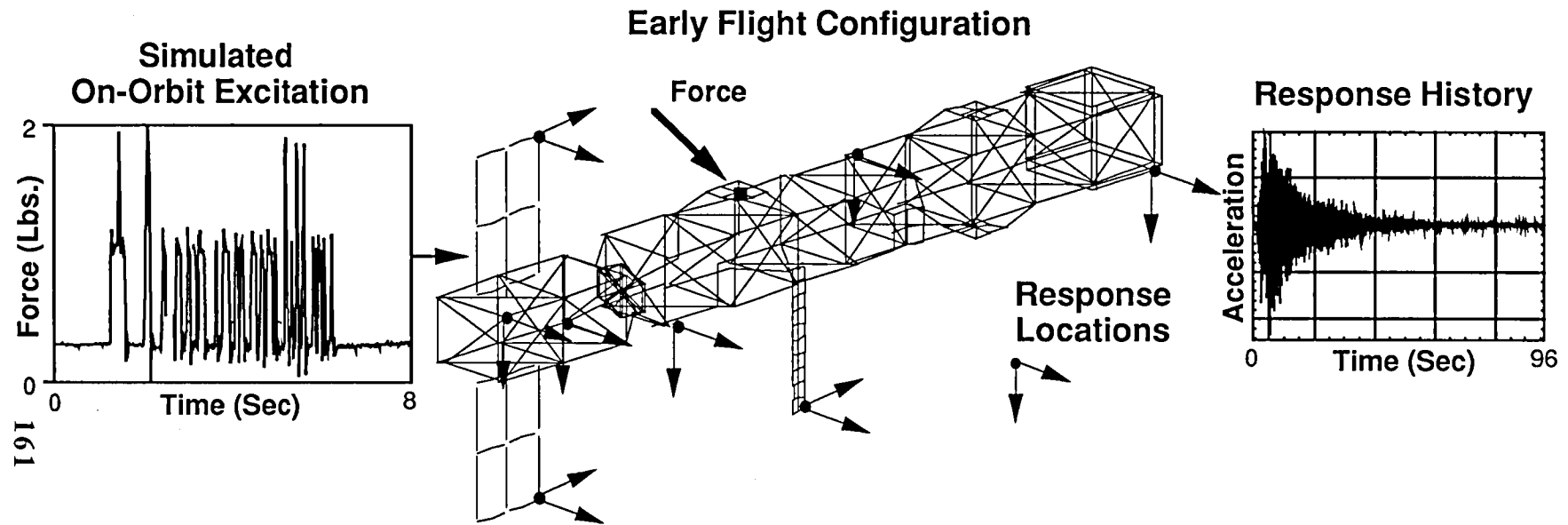
Accomplishment: A 1/10-size generic model representation of an early build space station configuration was suspended by cables and dynamically tested using conventional modal test techniques. Twenty vibration modes were identified and correlated with the finite element model within a 0-25 Hz bandwidth. Thirteen of these modes were identified as primary structural modes involving global truss motions. The modal test results provided a well-characterized structure for performing the MIE simulation tests. Excitations for the MIE simulations were provided by off-the-shelf laboratory shakers programmed to simulate the force pulse-train expected of the station-based thrusters. The accompanying figure indicates a typical pulse-train time history applied to the model at a single location. Additional tests were conducted using multiple thruster locations. Using only 16 response measurements, the MIE test results identified 11 primary modes using the Eigensystem Realization Algorithm (ERA). ERA is a time-domain parameter estimation method which is the baseline tool for the MIE.

Significance: On-orbit experiments require both analytical and experimental validation prior to implementation of excitation and measurement systems on the spacecraft system. However, structures such as space station are too large for fully assembled ground vibration tests. Development of a laboratory based simulation capability thus provides an early opportunity to examine experiment designs and a long term test-bed for further experiment development.

Future Plans: Additional tests using the DSMT 1/5:1/10 hybrid-scale model using updated sensor locations and additional thruster locations will be conducted. The MIE test matrix will be expanded to include more complex station configurations including dynamically scaled flexible appendages and representations of the station module cluster.

Figure 67 (a).

MIE SIMULATIONS VALIDATED BY GENERIC MODEL TESTS



MIE simulations correlated well with modal test results

	<u>MODAL TESTS</u>	<u>MIE SIMULATIONS</u>
# of sensors	96	16
# of shakers	2	1
# of modes identified	20	16
# of primary modes	13	11

Figure 67 (b).

SHORT RECORD MULTI-INPUT, MULTI-OUTPUT SYSTEM IDENTIFICATION TECHNIQUE DEVELOPED AND VALIDATED

Jer-Nan Juang, Minh Phan (LESC), Lucas G. Horta, and Richard W. Longman (NRC)

RTOP 590-14-21

Objective: The development of control laws for dynamic systems requires accurate mathematical models describing the relationship between inputs and outputs of the system. Analytically derived models are often inaccurate or unavailable. The objective of the research is to develop advanced system identification techniques for complex dynamical systems such as large space structures and flexible manipulators, including those which exhibit nonlinear behavior or have noisy measured data.

Approach: The traditional approach to system identification from measured input/output data is to assume a mathematical model of the system in parametric form. The same input $U(t)$ used to excite the physical system is applied to the model, and the output response $\Phi(t)$ of the model is computed. This response is compared to the measured response $Y(t)$ of the physical system, and the parameters of the mathematical model are updated or corrected to make $\Phi(t)$ match $Y(t)$. However, if there are significant measurement noises and/or system uncertainty, the identified model may be in error even though the output response is closely matched. Attempts to use the identified model to predict responses to inputs other than $U(t)$ will reveal the error. In the current research, an observer is used to isolate the model from measurement noises or unmodeled dynamics. Observers are often used to reconstruct the state of a system in the presence of noisy measurements or unmodeled dynamics.

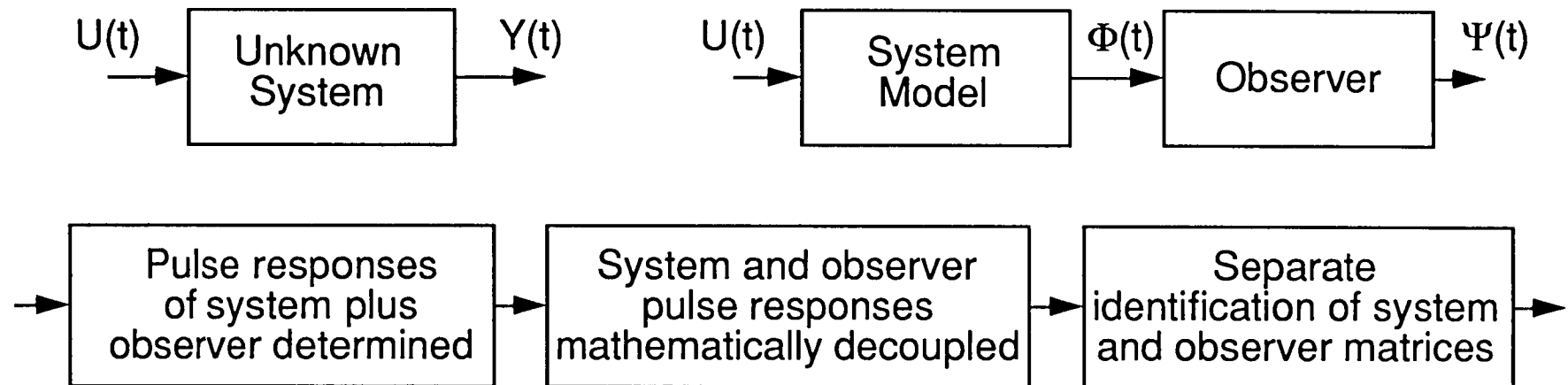
Accomplishment: A method was developed and implemented to obtain the pulse response of the assumed system and observer from the input data $U(t)$ and the measured response data $Y(t)$. A set of linear equations to mathematically decouple the pulse response of the model from the observer were derived. These decoupling equations are based on the limiting properties of observers and Kalman Filters, leading to the name Observer/Kalman Filter Identification or OKID for the method. Splitting the pulse response data leads to separate identification of the system model and observer using the Eigenvalue Realization Algorithm (ERA). In the example shown in the figure, a linear model and observer were identified for a highly nonlinear flexible manipulator system oscillating in response to a joint actuator input. The response of the identified model $\Phi(t)$ is shown compared to the measured response $Y(t)$, with good correlation until nonlinear effects become significant at low amplitudes. Comparison of the observer output $\Psi(t)$ with $Y(t)$ shows good agreement even at low amplitudes, indicating that the observer is correcting for the nonlinear dynamics of the system.

Significance: The identified model obtained by this method is more accurate than those of other approaches because the unmodeled dynamics and measurement noises are incorporated into an observer form. A more accurate model allows for higher performance control law designs with less stringent robustness requirements. Also, an observer identified from measured response data is available for direct use in observer-based control law designs. This greatly simplifies observer-based control law design because the specification of the unknown measurement noise often requires considerable engineering insight and judgement.

Future Plans: The OKID algorithms have currently been implemented in both batch (off-line) and recursive (on-line) modes. Ongoing research is focused on improving the recursive implementation to increase computational speed. Faster recursive implementations will allow for eventual adaptive or learning-control algorithms to control time-varying dynamical systems.

Figure 68 (a).

SHORT RECORD MULTI-INPUT, MULTI-OUTPUT SYSTEM IDENTIFICATION TECHNIQUE DEVELOPED AND VALIDATED



- Observer assumption and mathematical decoupling are significant theoretical advances
- Works with short time records, nonlinear systems, and forced response data
- Validated experimentally and analytically

Nonlinear flexible manipulator system results

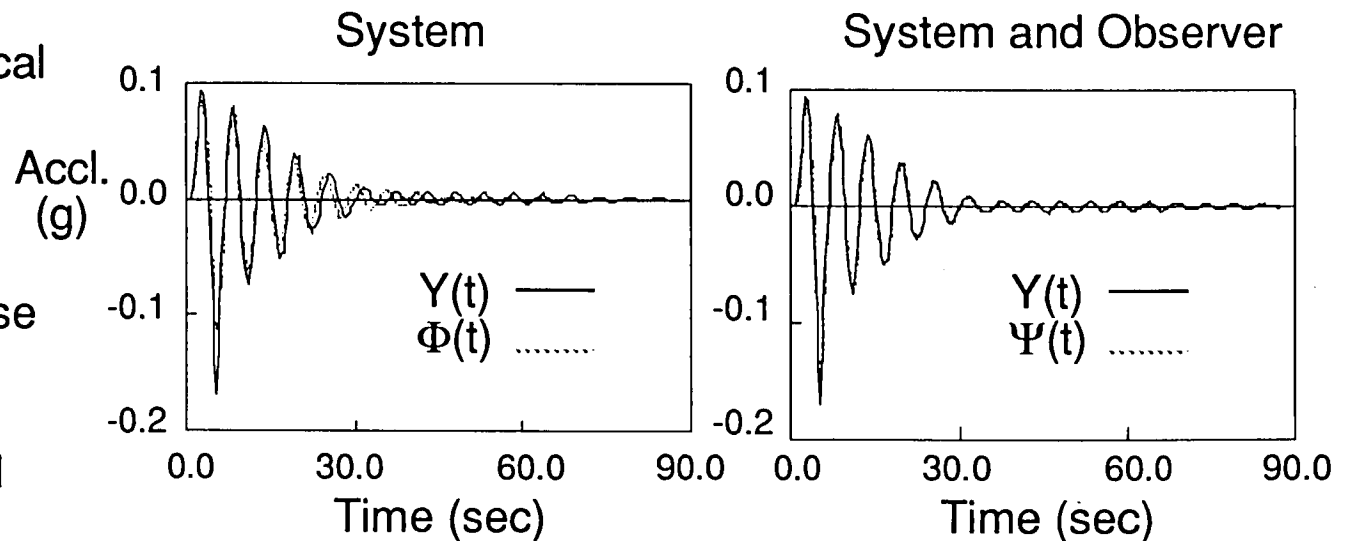


Figure 68 (b).

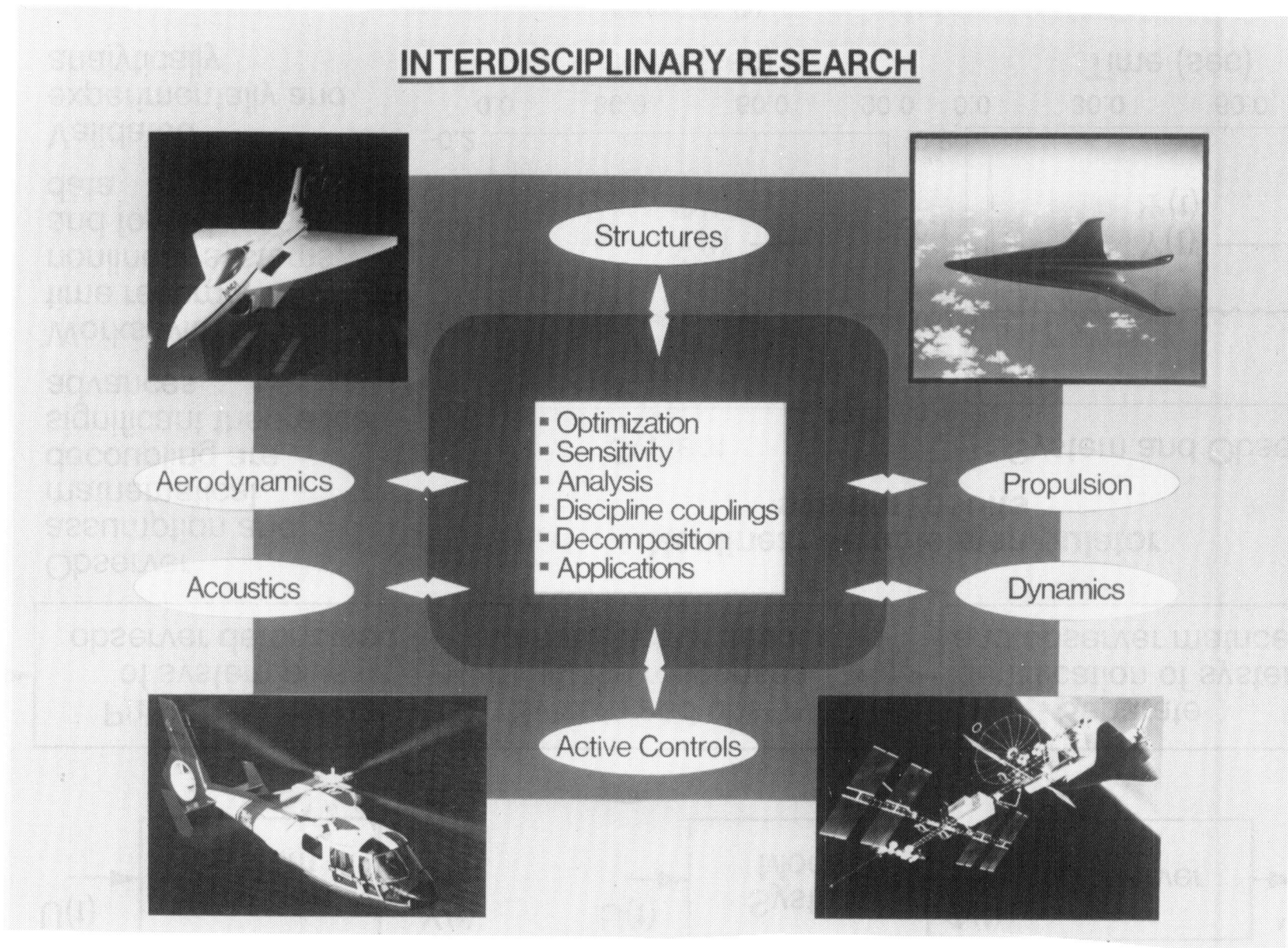


Figure 69.

INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 92-96)

GOAL

DEVELOP COMPREHENSIVE METHODOLOGY FOR OPTIMAL MULTI-DISCIPLINARY DESIGN

KEY OBJECTIVES

165

● METHODOLOGY

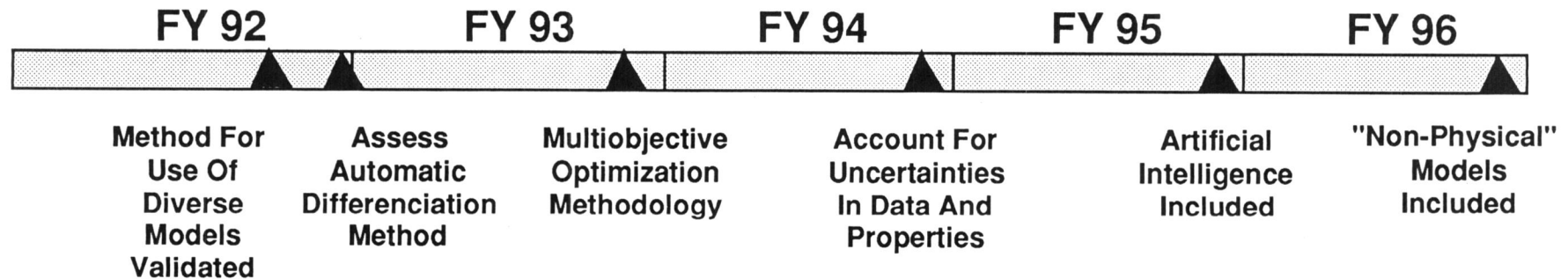


Figure 70 (a).

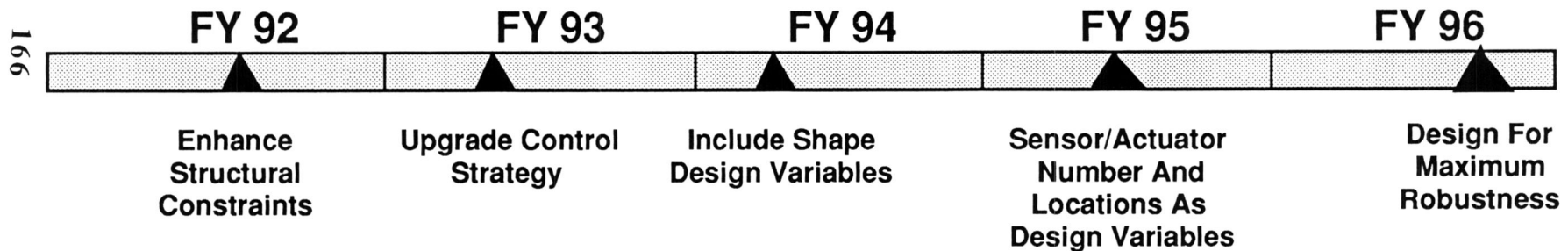
INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 92-96)

GOAL

DEMONSTRATE OPTIMAL DESIGN

KEY OBJECTIVES

● ACTIVE CONTROLLED SPACE STRUCTURES



● HIGH SPEED CIVIL TRANSPORT

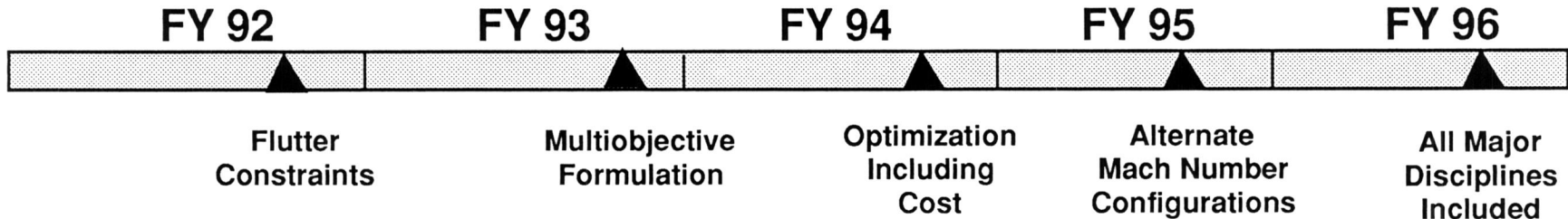


Figure 70 (b).

INTERDISCIPLINARY RESEARCH FUTURE PLANS (FY 92-96)

GOAL

DEMONSTRATE OPTIMAL DESIGN

KEY OBJECTIVES

● ROTORCRAFT

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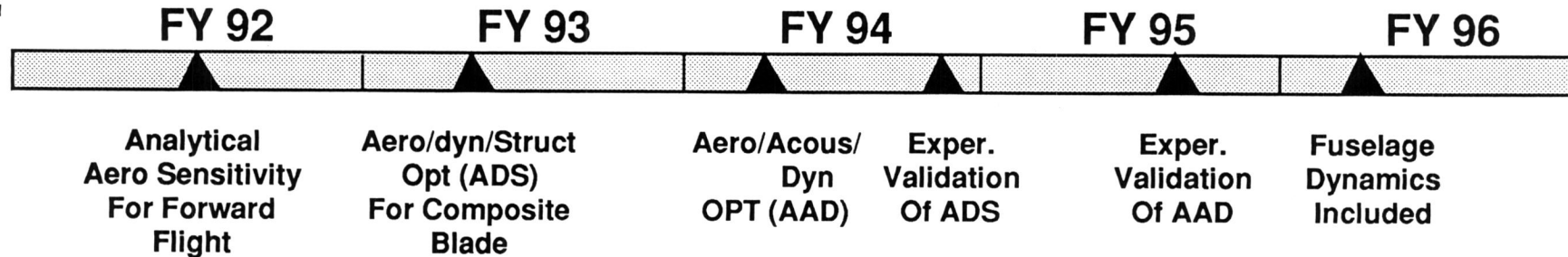


Figure 70 (c).

METHOD FOR TUNING MASS PLACEMENT REDUCES HELICOPTER ROTOR BLADE VIBRATION AND COMPARES WITH TEST DATA

Jocelyn I. Pritchard
Interdisciplinary Research Office

RTOP 505-63-36

Research Objective: Develop and validate a mathematical optimization procedure that systematically determines the best locations for tuning masses for reducing vibratory vertical hub shear in helicopter rotor blades. The method entails formulating an optimization procedure that employs the tuning masses and their locations as design variables to minimize vertical hub shear without a large mass penalty.

Approach: Combine optimizer with a comprehensive helicopter analysis code (CAMRAD/JA) to calculate mode shapes, frequencies, airloads and hub shears. The optimization procedure systematically decides where and how much mass is needed to reduce the shear without a large mass penalty. Bounds are placed on the first two flapwise frequencies to avoid resonance. Optimal placement of the mass tailors the mode shapes and airloads thus reducing generalized force and response of the blade. The use of CAMRAD/JA enables the variation in the airloads due to changes in the design variables to be taken into account.

Accomplishment Description: The procedure has been applied to a blade test article that has the capability for adding tuning masses along the blade span. The test article, designed to study passive means for minimizing fixed-system loads, was tested in the Langley Transonic Dynamics Tunnel and provided an opportunity to validate the optimization procedure. The test data included 4/rev hub shear as a function of the location of a tuning mass of 0.27 lbf for several flight conditions. The graph shows the comparison between the optimization results and the test data for three advance ratios. The test data is shown as a range because the data was only available at 10% increments along the span. The optimization procedure was able to predict an optimum location that was within the optimum range of the test data for two advance ratios .25 and .35. The third case was within 12% of being in the range. This is fairly good agreement considering the difficulty of predicting fixed-systems loads with existing analysis codes.

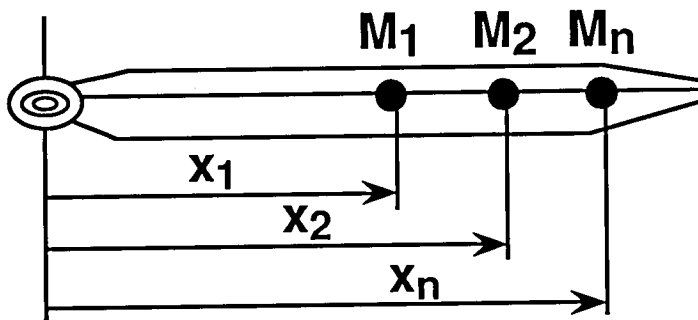
Significance: The use of tuning mass addition has been shown to be successful in reducing vibration in helicopter rotor blades. Conventionally, the masses and locations are varied by trial and error. This optimization procedure provides the capability to systematically determine the best sizes and locations for the masses.

Future Plans: Plans are to validate the optimization procedure for a multiple mass configurations. Additionally, it was noted that while the optimum locations were predicted fairly well, the absolute magnitudes of the hub shears were not. Additional work is therefore needed in this area to understand the reasons for the inaccuracy of fixed-system loads prediction and initiate research for improvement of this capability.

Figure 71 (a).

METHOD FOR TUNING MASS PLACEMENT REDUCES HELICOPTER ROTOR BLADE VIBRATION AND COMPARES WITH TEST DATA

Problem definition - selection of optimum locations for tuning masses



- Design goal - Find optimum combination of masses and their locations to reduce vertical hub shear
- Method - Formulate optimization procedure
 - Use masses and locations as design variables
 - Minimize
 - Vertical hub shear
 - Added mass

Optimum location versus advance ratio

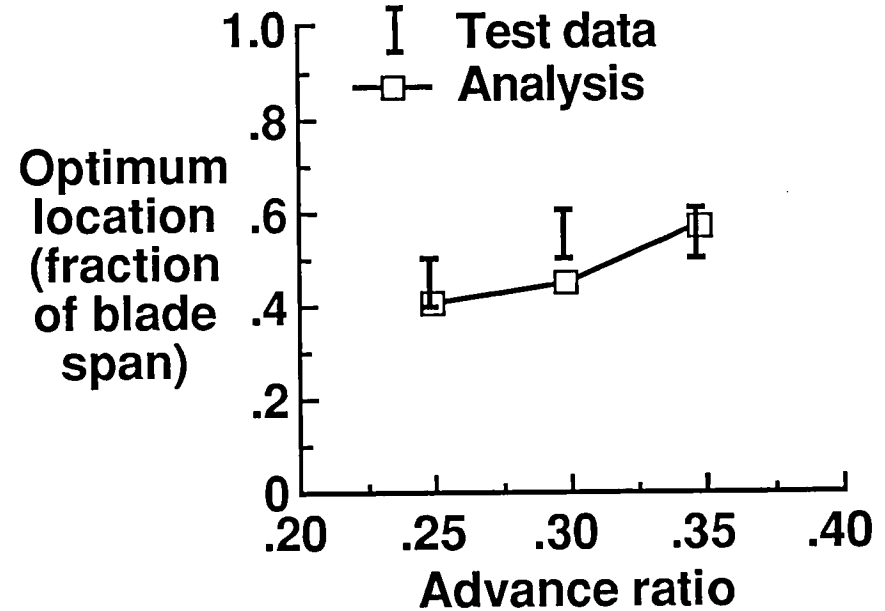


Figure 71 (b).

FULLY INTEGRATED AERODYNAMIC/DYNAMIC OPTIMIZATION PROCEDURE FOR HELICOPTER ROTOR BLADES DEMONSTRATED

Joanne L. Walsh and Howard M. Adelman
Interdisciplinary Research Office

William J. LaMarsh, II, UNISYS Corporation

RTOP 506-63-36

Research Objective: This work is part of a Langley Research Center effort to integrate appropriate disciplines in the rotor blade design process. The present procedure accounts for aerodynamics (loads), performance, and dynamics simultaneously.

Approach: A procedure is developed to optimize the aerodynamic and dynamic performance of rotor blades (fig. 72 (b)) by determining the maximum pretwist τ_{\max} , the point of taper initiation r/R , taper ratio c_r/c_t , root chord c_r , blade stiffnesses, tuning masses and their locations which minimizes a composite objective function (a linear combination of horsepowers required for hover HP_{hover} , forward flight HP_{ff} , maneuver HP_m , and 4 per rev hub shear for forward flight $S_{4\text{ff}}$). The procedure uses HOVT (a strip theory momentum analysis) to compute hover horsepower and the comprehensive helicopter analysis program CAMRAD/JA for forward flight performance and dynamics. The optimization algorithm consists of the general purpose optimization program CONMIN and approximate analyses. Constraints include limits on required horsepowers, frequencies, avoidance of drag divergence, weight, autorotational inertia, and tip chord.

Accomplishment Description: The procedure has been applied to show that it can produce a design close to that of an existing wind tunnel model of a growth utility rotor blade. Figure 72 (c) includes the shape and response for the initial trial, optimized, and actual blades. The figure includes performance and dynamics measures (horsepowers for hover, forward flight, and maneuver and the 4 per rev forward flight vertical shear). The Optimized Design was the design obtained with $k_1=1$, $k_2=k_3=0.5$, and $k_4=0.05$. As shown in Figure 72 (c), the optimization procedure produced a blade which had performance measures quite close to that of the existing blade. The optimized blade was similar in planform to the actual blade. Specifically, the root chord was 4.1 in, the taper ratio was 1.8, the point of taper initiation was 0.81, and the maximum pretwist was -16 degrees. For the actual blade these values were 5.4 in, 3.0, 0.80 and -16 degrees, respectively.

Significance: This optimization procedure incorporates an industry-standard analysis code CAMRAD/JA. The procedure constitutes a critical step toward the goal of a fully integrated rotor blade design optimization capability which will include structures and acoustics.

Future Plans: Design of the internal structure will be incorporated by adding another level which sizes a wing box inside the airfoil. This will produce an integrated aerodynamic/dynamic/structural optimization procedure for rotor blade design.

Figure 72 (a).

FULLY INTEGRATED AERODYNAMIC/DYNAMIC PROCEDURE FOR HELICOPTER ROTOR BLADES DEMONSTRATED

- Objective function = $K_1 HP_H + K_2 HP_{FF} + K_3 HP_M + K_4 S_4_{FF}$
- Design variables
 - $\tau_{max}, r/R, c_r/c_t, c_r$
 - Blade stiffnesses
 - Tuning masses and locations
- Constraints
 - Horsepower required
 - Trim
 - Stall
 - Frequencies
 - Autorotational inertia
 - Maximum blade weight
 - Minimum tip chord

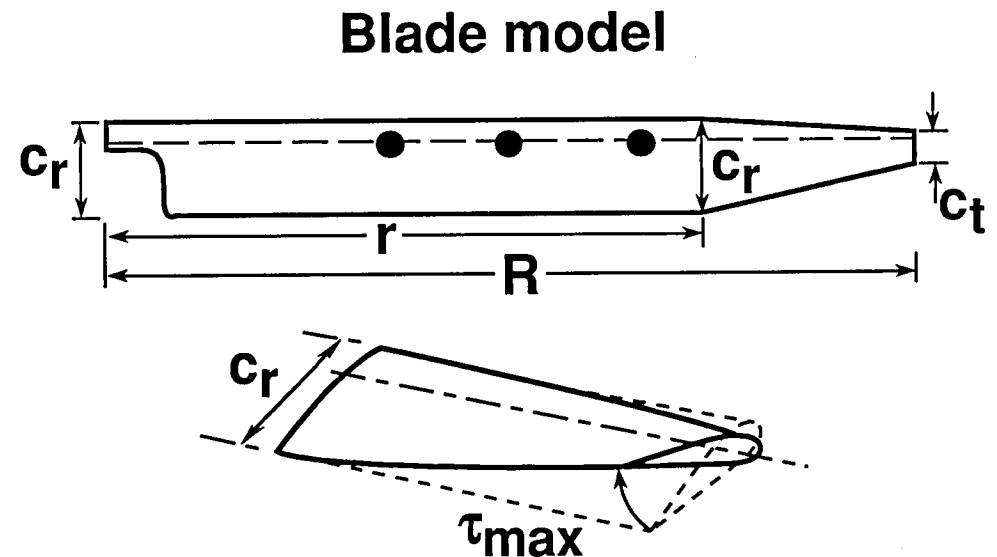


Figure 72 (b).

FULLY INTEGRATED AERODYNAMIC/DYNAMIC OPTIMIZATION PROCEDURE FOR HELICOPTER ROTOR BLADES DEMONSTRATED




	Initial trial design	Optimum design	Actual blade
			
Hover hp	15.35	14.41	14.84
Forward flight hp	13.52	12.54	13.13
Maneuver hp	12.26	11.78	11.83
4 per rev hub shear lbf	2.19	1.17	1.52

Figure 72 (c).

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HiSAIR/Pathfinder Generates Minimum Weight Designs for Mach 3 Transport Configuration

Jean-Francois M. Barthelemy
Interdisciplinary Research Office

G.A. Wrenn and A.R. Dovi, Lockheed Engineering and Sciences Corporation

Peter G. Coen, Vehicle Integration Branch, Aeronautics Directorate

RTOP 505-63-50-06

Research Objective: The HiSAIR/Pathfinder project aims at demonstrating an approach to design integration based on disciplinary analysis and sensitivity analysis capabilities and formal optimization methodology.

Approach: The initial focus of the Pathfinder activity is a three discipline integration exercise that is to maximize aircraft performance with respect to structural and basic wing configuration variables while satisfying constraints on structural integrity and minimum performance requirements. Basic analysis modules include the following Langley-developed computer programs: ELAPS for structural analysis of a plate model of the aircraft, the linear aerodynamics code WINGDES for prediction of airloads and drag due to lift and FLOPS for estimation of basic performance characteristics. Optimization is based on the OPTDES commercial nonlinear optimization package while data management is largely done with RIM, a relational database.

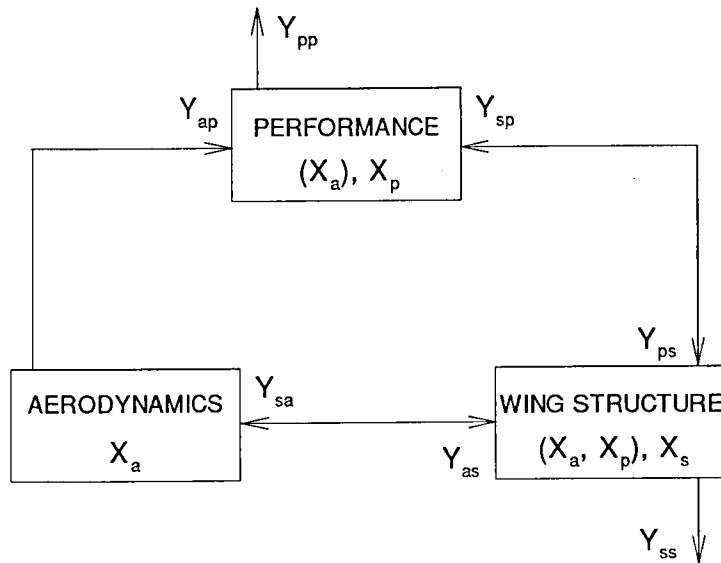
Accomplishment Description: Work has concluded on a M 3.0 transport configuration. The optimization system currently includes aerodynamic and structures modules and provides the capability for minimum weight structural design; analysis and sensitivity analysis take into account the elastic redistribution of loads. The figure shows weight convergence for a series of 4 design exercises conducted under different hypotheses. The initial design is with a fictitious Titanium-based metal-matrix composite material used in a quasi-isotropic lay-up. Wing rib and spar caps are made of pure titanium. 45 variables describe the model; successive designs raise the wing panel minimum gauge, thin out the wing panel sandwich core and switch to an all-Titanium material.

Significance: When completed, this system will provide for a first implementation of a design tool that considers directly the impact that aerodynamic and structural design have on aircraft performance. The integration approach used is generic however and the demonstrated methodology is expected to be applicable to any complex design problem.

Future Plan: Work is underway to continue developing the system, providing initially for a capability that integrates both aerodynamic and performance modules and that permits aircraft configuration design. Then all three modules will be integrated together permitting simultaneous configuration and structural design for optimum performance. The system is now being used to design a M 2.4 configuration.

Figure 73 (a).

HiSAIR/Pathfinder Generates Minimum Weight Designs for Mach 3 Transport Configuration



- Three disciplines combined to include important coupling effects
- Initial implementation uses linear analyses

- Current implementation performs minimum weight design under flexible loads
- Designs satisfy constraints on stresses, strains and buckling of wing skin panels and spar and rib caps

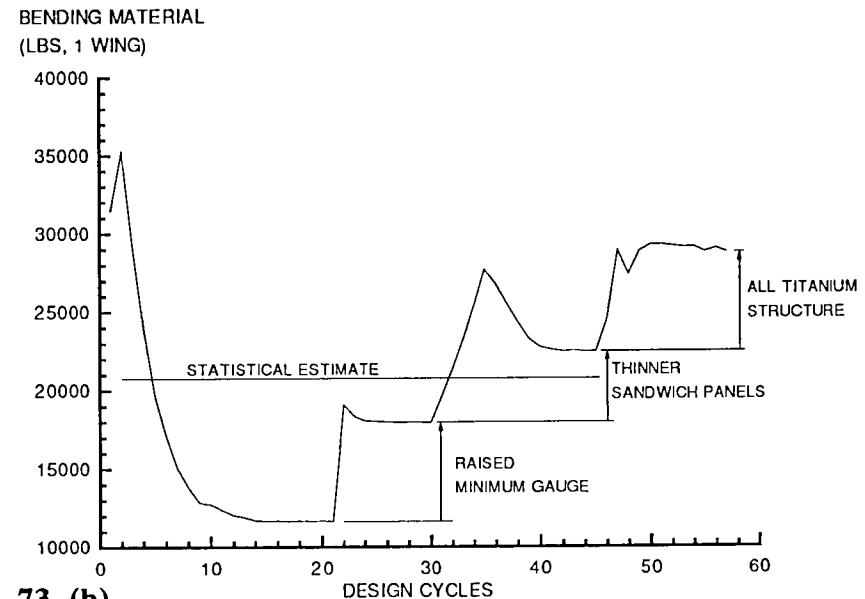


Figure 73 (b).

SYSTEM SYNTHESIS BY CONCURRENT SUB-OPTIMIZATIONS DEMONSTRATED FOR CONTROL-AUGMENTED STRUCTURE

Christina L. Bloebaum, University of Florida and Prabhat Hajela, Rensselaer Polytechnic Institute
Jaroslaw Sobieski, Interdisciplinary Research Office

RTOP 509-10-02

Research Objective: Develop and validate a synthesis methodology to perform concurrent optimizations for highly coupled multidisciplinary systems. Such a methodology allows for the application of specialized methods for analysis and optimization within each discipline, while accounting for the interdisciplinary couplings and trade-offs.

Approach: Large scale engineering design problems are often characterized by multidisciplinary interactions in which participating disciplines are intrinsically linked to one another. The interdependencies of discipline analysis modules in such applications contributes to difficulties in successfully implementing a holistic design synthesis strategy. The development of a methodology that allows simultaneous consideration of all system design criteria is both a necessity and a challenge.

The flowchart on the attached figure summarizes a new approach for multidisciplinary synthesis in which variables (r and t) provide coordination during decoupled concurrent optimizations. In the two-discipline example involving structures and controls, the r variable represents the responsibility of the controls discipline for satisfying the structures constraints. Similarly, the t variable represents the structural constraint relaxation which is compensated for by the controls design variables. Following concurrent sub-optimizations, in which the objective is to minimize the total system weight, a heuristics-based coordination problem yields updated values of the r and t variables for use in the next cycle. The design process repeats until no further reduction in weight can be obtained.

Accomplishment Description: The method was applied to the controls-augmented ten-bar truss shown in the attached figure. The structure was subjected to static and dynamic loadings, with design constraints derived from both the structures and controls disciplines. A graph demonstrating the convergence history for the system weight and variables is shown in the figure. A rapid decrease in weight was obtained in the first 5 cycles when the trade-off variable was active. The responsibility variable then activated to assure constraint satisfaction for the next 5 cycles, with a trade-off once again being permitted for the next 5. A smooth convergence was obtained for the objective function, with an almost 50% improvement in weight.

Significance: The method is among the first to successfully perform sub-optimizations within each discipline concurrently, allowing for substantial autonomy within each disciplinary design group, and yet providing appropriate coordination of the disciplines as components in a coupled system.

Future Plans: Implementation of the approach in a more complex, highly coupled multidisciplinary problem, with further investigation of the applications of artificial intelligence concepts, including neural networks in the system sensitivity analysis.

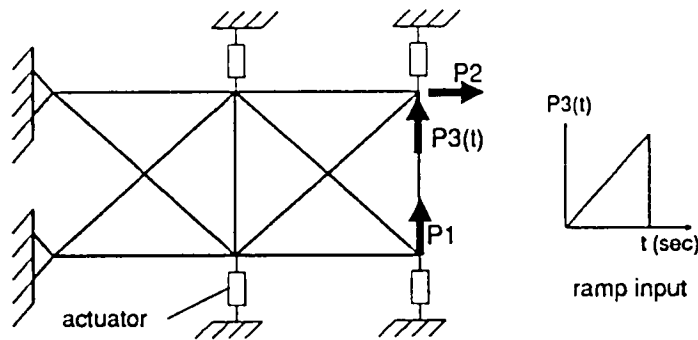
Figure 74 (a).

SYSTEM SYNTHESIS BY CONCURRENT SUB-OPTIMIZATIONS DEMONSTRATED FOR CONTROL-AUGMENTED STRUCTURE

PROBLEM

How to distribute system optimization task among participating coupled disciplines.

TEST CASE



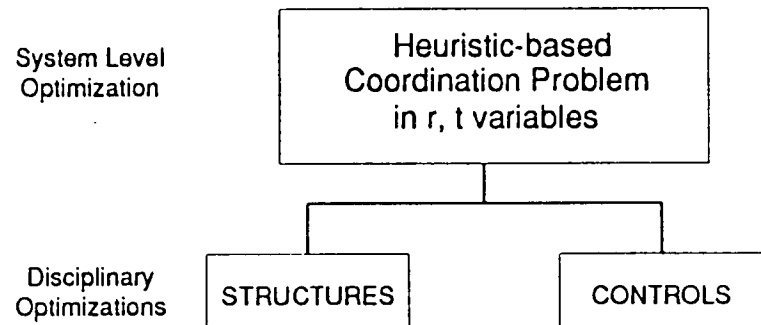
DESIGN OBJECTIVE: Total System Weight

DESIGN CONSTRAINTS: Natural Frequencies
Static Stresses & Displacements
Dynamic Displacements

DESIGN VARIABLES: Truss Member Areas
Damping Constant

APPROACH

Two-discipline Example



r - "responsibility" variable, e.g. % of overstress to be removed by controls.
 t - "trade-off" variable, e.g. % of stress constraint relaxation to be compensated by controls. Structural mass traded for control mass.

SAMPLE RESULT

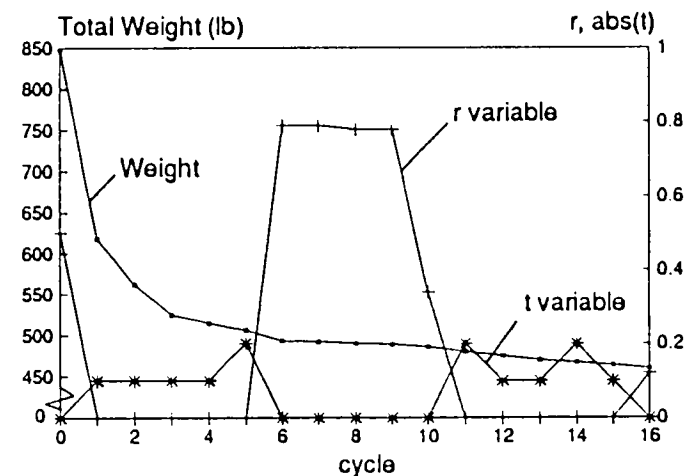


Figure 74 (b).

NEW METHOD CONTROLS THERMAL DISTORTION OF SPACE ANTENNAS

Robert H. Tolson
Interdisciplinary Research Office

RTOP 506-43-41

Research Objective: To develop a control system design method that (1) recognizes the time dependence of thermal distortion due to orbital motion and (2) controls variables that directly relate to antenna performance.

Approach: Large, high frequency space antennas require such accurate reflecting surfaces that a control system may be required to maintain the accuracy. Past control system designs ignored the time dependence of the distortion and used surface RMS deviation as the measure of performance. This study overcomes the first limitation by expanding the distortion in principal components that are orthogonal in space and time. Optimal actuator strokes, to correct the distortion, are a linear combination of the time dependent components. The spatial components provide a natural space in which to determine the optimal actuator locations and also act as basis vectors for extrapolating sensor measurements to the entire antenna surface. To overcome the second limitation, a new objective function is obtained by expanding the far zone electric field in a Zernike-Bessel series. The coefficients of this series provide a reliable measure of far field performance and a natural cost function for designing the control system. The method accommodates tapered feeds and arbitrary polarizations.

Accomplishment: Simulations, using the 55 m diameter geosynchronous radiometer shown in the figure, demonstrate the utility of the method. The ideal far field pattern of the undistorted antenna has a well defined center beam and side lobes below -30 dB. The thermally distorted pattern has neither important characteristic. The control system, designed by the new method, proved to be very robust to errors in structural materials, thermal properties and heating conditions. In the worst case, shown in the figure, only 11 actuators and 19 sensors are required to produce an acceptable pattern.

Significance: This study identified an easily calculated objective function that reliably predicts antenna performance and can also be used to evaluate other types of reflecting surface errors, e.g. vibration and manufacturing errors. The inclusion of the time dependence of the thermal distortion provides an effective means of optimal control system design that is applicable through out the antenna orbit.

Future Plans: The Zernike-Bessel expansion, used to develop an analytic cost function, may provide a numerically efficient means of calculating far field patterns of slightly distorted antennas. A study will be performed to evaluate this possibility.

Figure 75 (a).

NEW METHOD CONTROLS THERMAL DISTORTION OF SPACE ANTENNAS

PROBLEM

- Require very accurate surfaces to meet RF performance
- May need active control for thermal distortion
- Previous control system studies:
 - Ignored time dependence of distortion

Performance based on simple root mean square surface deviation

METHOD

- Cost function directly related to RF performance and control parameters
- Optimal control system based on time dependent distortion

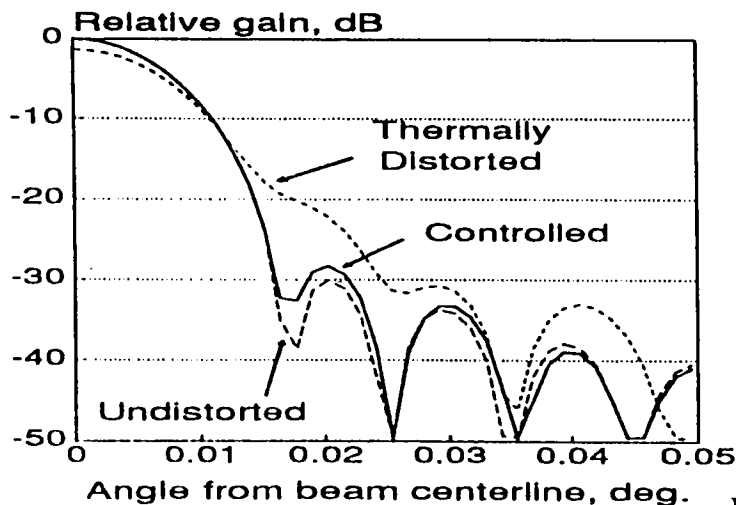
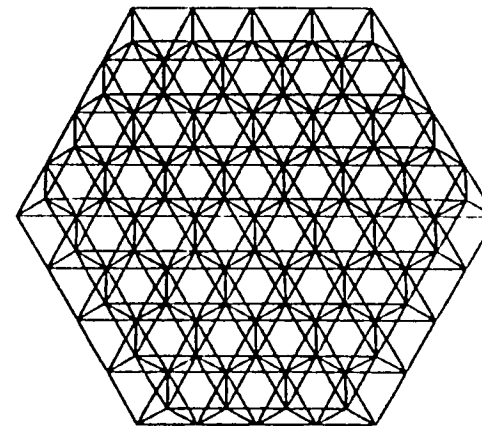


Figure 75 (b).



Test Problem:

11 Actuators & 19 Sensors

INTEGRATED OPTIMIZATION ALLOWS FAVORABLE TRADE OF STRUCTURAL MASS FOR CONTROL EFFORT

Sharon L. Padula
Interdisciplinary Research Office

RTOP 506-43-41

Research Objective: To develop multidisciplinary optimization methods for design of controlled space structures.

Approach: Future Agency missions envision controlled space structures which routinely damp out vibrations excited by pointing maneuvers. Preliminary design of these spacecraft is complicated by controls-structures interaction (CSI). Specifically, changes in the structure impact the control system design by modifying both the plant to be controlled and the expected excitation. At the same time, changes in the control system impact the structural design by modifying the number, mass and location of actuators. The preliminary design of a generic geostationary platform (see figure 76 (b)) is used to develop CSI optimization methods. The goal is to reduce the total mass of the structure and the vibration control system while satisfying performance constraints on vibration decay rate. There are 3 structural design variables which size truss elements and 12 control design variables which determine entries in the rate and position gain matrices. Standard finite element analysis, optimal control and mathematical programming routines are coordinated by a new multidisciplinary optimization scheme.

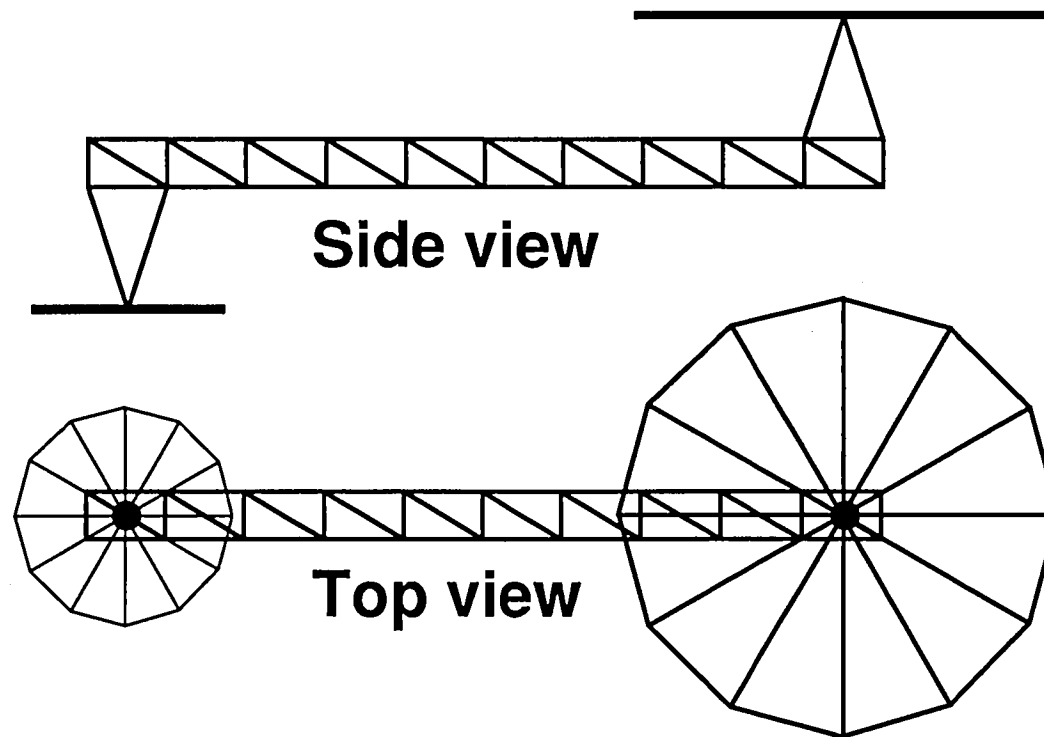
Accomplishment: The platform is successfully redesigned so that the mass distribution and dynamic characteristics of the structure enhance the use of rate and position feedback by the control system. Figure 76 (c) a typical convergence history of the optimization process, indicates a 300 kilogram reduction in structural mass can be traded for a 58 kilogram increase in actuator mass. The procedure not only makes a favorable trade of structural mass for control effort but improves the vibration decay rate as well.

Significance: This research demonstrates that an integrated controls-structures optimization method can lead to significant mass savings which would not be revealed by traditional (single discipline) design methods.

Future Plans: This research is the first step toward a general purpose integrated controls-structures design method for large space structures subjected to frequent positioning maneuvers. The present method is simplified in that the number and location of actuators and sensors is fixed and in that stress and buckling considerations are ignored. The next research phase will calculate stresses caused by the dynamic response of the controlled structures and include yield stress constraints.

Figure 76 (a).

INTEGRATED OPTIMIZATION ALLOWS FAVORABLE TRADE OF STRUCTURAL MASS FOR CONTROL EFFORT



Problem:

- Minimize mass of structure and actuators
- Achieve required vibration decay rate
- Use 15 design variables (3 truss sizes + 12 gains)

Figure 76 (b).

INTEGRATED OPTIMIZATION ALLOWS FAVORABLE TRADE OF STRUCTURAL MASS FOR CONTROL EFFORT

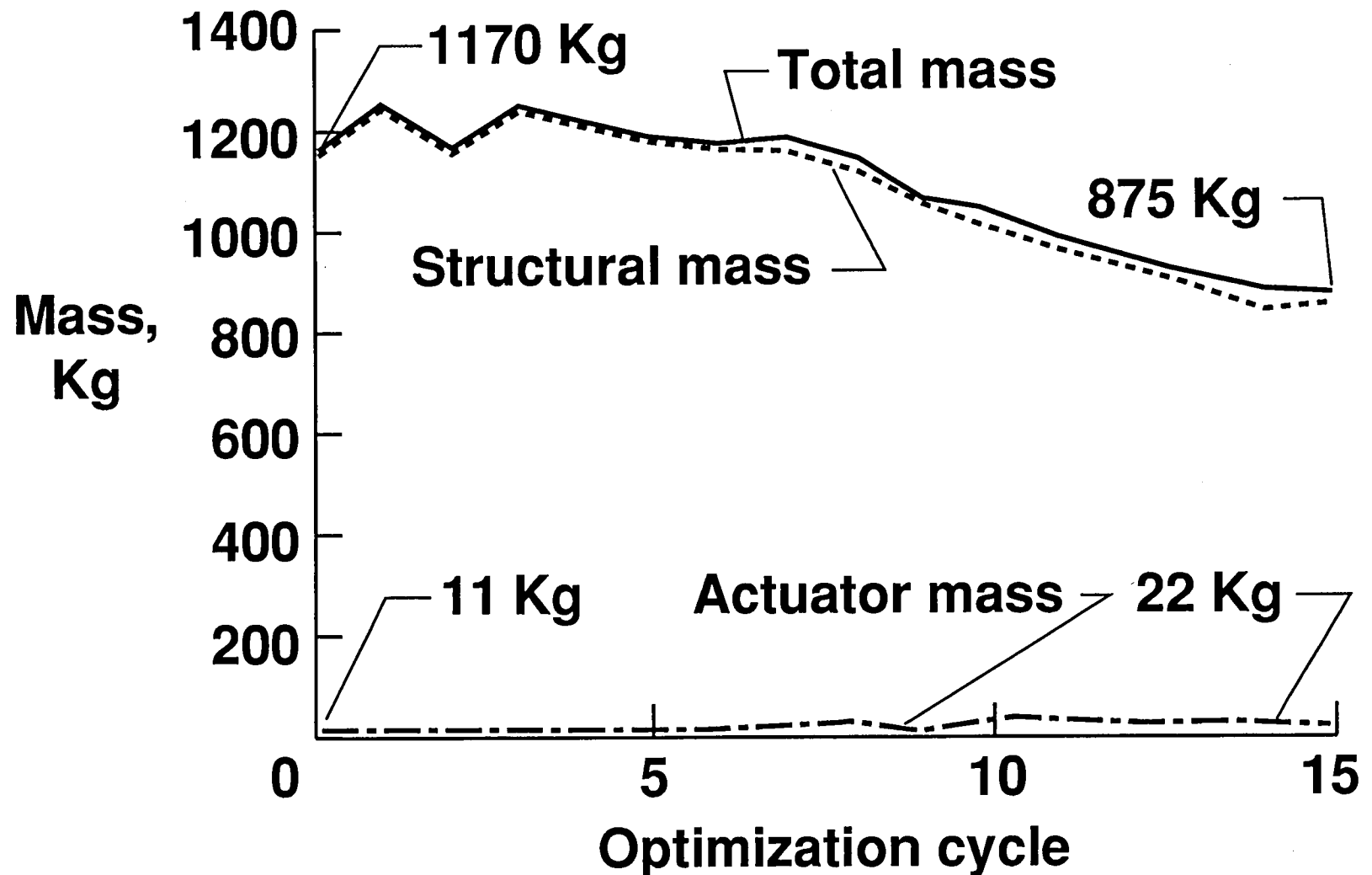


Figure 76 (c).

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SENSITIVITY-BASED SCALING FOR APPROXIMATING STRUCTURAL RESPONSE

Kwan J. Chang, LESC, Raphael T. Haftka, VPI & SU
Gary L. Giles, Interdisciplinary Research Office and Pi-Jen Kao, AS & M

RTOP 505-63-50

Research Objective: To improve the effectiveness of structural optimization procedures by developing a sensitivity-based linearly varying scale factor which permits the use of a simplified model in an optimization procedure during preliminary design whose results are scaled to approximate the response given by a refined model over a considerable range of design changes.

Approach: Two different formulations are used to analyze the same structure; a simplified representation using an equivalent-plate analysis method and a refined representation using a conventional finite-element program. The simplified analysis computationally-efficient but produces approximate results and the refined analysis is computationally-expensive but produces accurate results. Traditionally a constant factor, $B(x_0)$, based on a single design point has been used to scale results between the simple and refined models of the same structure as shown by the first equation in the figure. The derivative of this scale factor with respect to a design variable, $B'(x_0)$, can be calculated and used to provide a linearly varying scale factor as shown in the second equation. During optimization the simplified analysis results can be calculated and then scaled using either the constant or linear varying factor, $f_{sro}(x)$ or $f_{srl}(x)$, the provide an approximation to the more accurate (refined) analysis results.

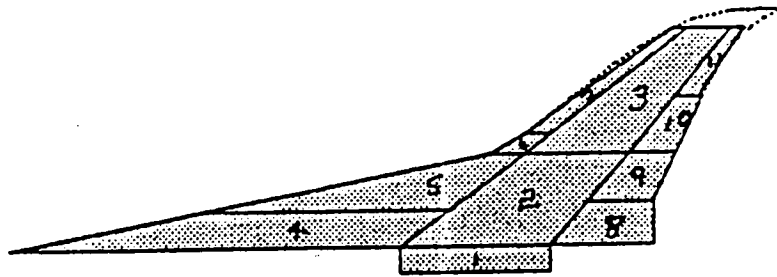
Accomplishment Description: The method has been tested using the wing box structure shown in the figure as an example, with displacements, stresses and frequencies correlated. In the figure, results for the wing tip displacement are shown. The results from both the equivalent plate analysis and finite element analysis are given for a range of changes in a specified design variable (up to a factor of 3 change). The relative accuracy of the approximate responses which are given when the constant and linear varying scale factors are applied to results from the equivalent plate analysis are shown as well as the commonly used tangent method. Such results demonstrate that the linear scale factor gives good correlation with the refined analysis results over a considerable range of changes in design variables.

Significance: This linear scaling method provides a new approach for approximating structural response which should prove to be effective when applied in overall optimization procedures. The effectiveness of the method is achieved by providing a mechanism to reflect the accuracy of a refined (accurate), computationally-expensive model in the results of a simplified (approximate), computationally-efficient model used in the optimization. Moreover, the method is not limited to structural applications and can be used by other disciplines to correlate responses from different analytical models.

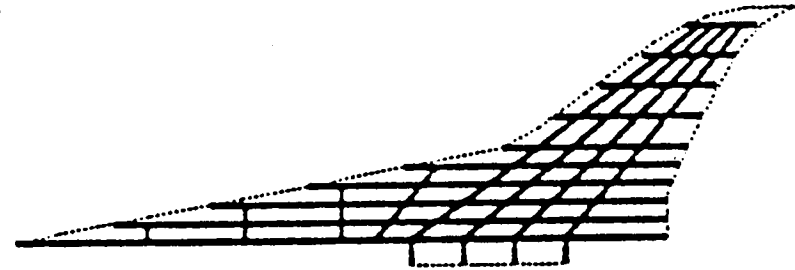
Future Plans: Take advantage of the benefits of this scaling method for in-house design studies of vehicles of interest such as a high speed civil transport (HSCT) in which the level of refinement of the finite element modeling will be significantly increased over that used for testing of the method.

Figure 77 (a).

SENSITIVITY-BASED SCALING FOR APPROXIMATING STRUCTURAL RESPONSE



EQUIVALENT PLATE
(SIMPLIFIED - S)



FINITE ELEMENT
(REFINED - R)

SCALE FACTORS

$$\beta(x_0) = f_R(x_0) / f_S(x_0)$$

$$\beta(x) = \beta(x_0) + (x - x_0) \beta'(x_0)$$

$$\beta'(x_0) = d\beta(x_0) / dv$$

$$f_{SR0}(x) = \beta(x_0) f_S(x)$$

$$f_{SR1}(x) = \beta(x) f_S(x)$$

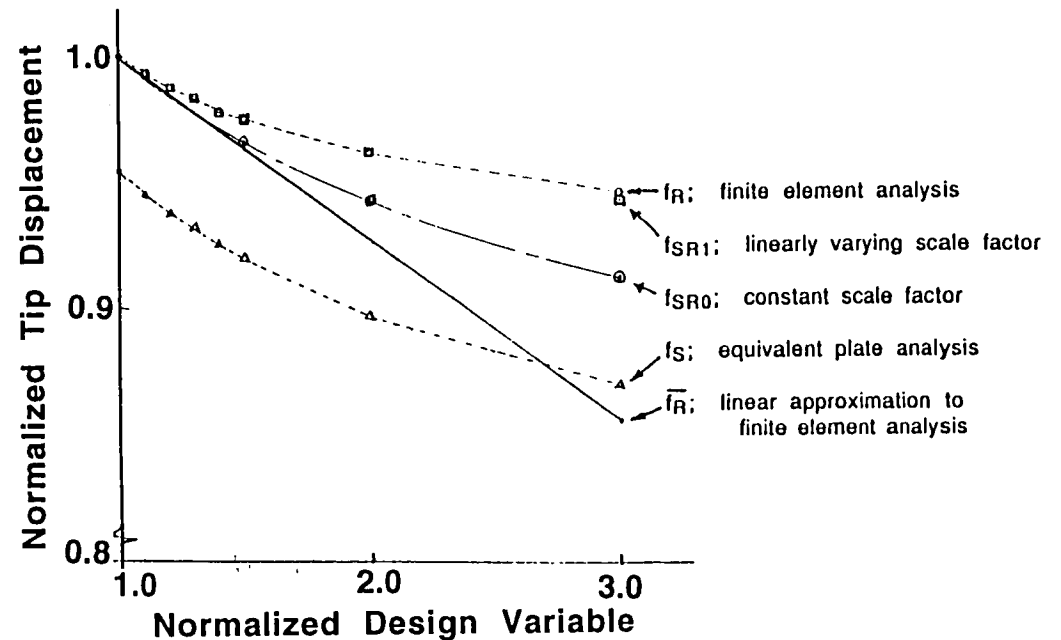


Figure 77 (b).

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CONFIGURATION AEROELASTICITY

F.Y. 1992 PLANS

- **Complete CofF project to modify TDT Heavy Gas Reclamation System**
- **Complete the TDT test of Supercritical Airfoil Benchmark Model**
- **Complete Limit Cycle Oscillation (LCO) tests on transport flutter model in the TDT**
- **Complete tests in TDT to determine performance characteristics of BERP-type rotor**
- **Complete the first TDT test of the Active Controls Benchmark Model**
- **Complete fabrication of baseline helicopter rotor blades in support of Langley optimization validation effort**
- **Complete hypersonic tests of component wing flutter model in Hypersonic Helium Tunnel**
- **Complete design and fabrication of transonic flutter model of NASP engine**
- **Complete simple NASP panel flutter model tests in the Unitary Plan Wind Tunnel**

Figure 78.

AIRCRAFT AEROELASTICITY

Maynard C. Sandford
Configuration Aeroelasticity Branch

RTOP 505-63-50
RTOP 763-23-41

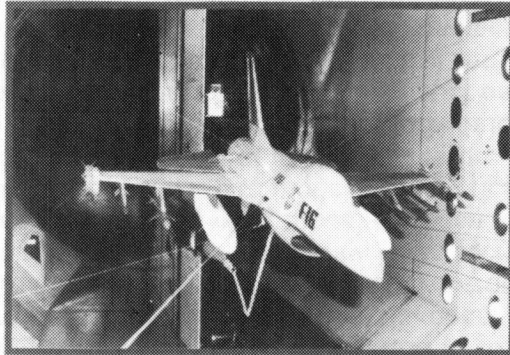
Research Objective: The objectives in the aircraft aeroelasticity technical area are to determine and solve the aeroelastic problems of current designs, and to develop the aeroelastic understanding and prediction capabilities needed to apply new aerodynamic and structural concepts to future flight vehicles.

Approach: The types of research included in the aeroelasticity area are illustrated in the accompanying figure. This research is a combination of experimental and complementary analytical studies. The experimental work focuses on the use of the Langley Transonic Dynamics Tunnel (TDT) which is specifically designed to meet the unique needs of aeroelastic testing. On occasion flight research programs are undertaken when it is necessary to simulate important parameters that cannot be accurately accounted for in ground-based facilities. Often research is a cooperative effort with other government agencies and/or industry.

Status/Plans: Work for the coming year includes several activities, some of which are described as follows. Analytical and experimental investigations will continue to provide flutter data to support development of subsonic transports and the National Aero-Space Plane (NASP). Two joint studies are planned with the Boeing Commercial Aircraft Company in 1992. The first study involves a test of a transport type wing model, scheduled for TDT in January, to investigate phenomena which cause limit cycle oscillations (LCO). The second study is a flutter evaluation of the new 777 aircraft with a model to be tested in the TDT scheduled for March. There is also a cooperative effort with Cessna to study flutter characteristics of the Citation X transport configuration in the TDT scheduled for September 1992. Work will continue on three NASP Government Work Packages (GWP) which were started in 1991. For GWP 71 (Vehicle Flutter Evaluation) several simple wing models have been constructed and are being prepared for tests which are scheduled to start in late 1991 in the Langley Hypersonic Helium Tunnel. This will be followed by supersonic tests of a cantilevered wing-only model in the Langley Unitary Facility during April 1992. A simple fuselage-flexibility model of an acceptable generic configuration is now in the design stage with a test in the TDT in August 1992. For GWP 71A (Engine Flutter Evaluation) a simple engine configuration is presently being designed and built in-house for a test in TDT in December 1991 for a quick look at a suspected divergent instability. GWP 74 (Panel/Shell Flutter) is a cooperative effort with Wright-Patterson Laboratory for a supersonic panel flutter test in the Langley Unitary Facility scheduled for April 1992.

AIRCRAFT AEROELASTICITY

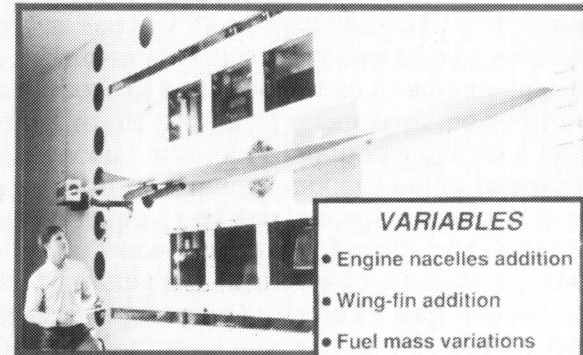
CLEARANCE STUDIES



RESEARCH AREAS

- Flutter
- Divergence
- Active/passive controls
- Aeroelastic tailoring
- Test techniques
- Buzz
- Buffet

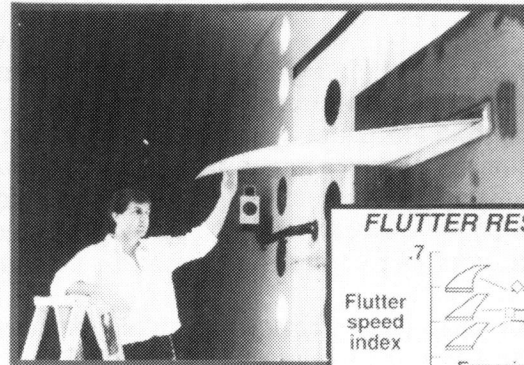
CONFIGURATION STUDIES



VARIABLES

- Engine nacelles addition
- Wing-fin addition
- Fuel mass variations
- Angle of attack changes

BASIC STUDIES



FLUTTER RESULTS

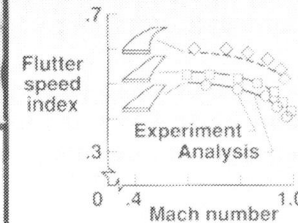


Figure 79 (b).

BENCHMARK MODELS

Michael H. Durham
Configuration Aeroelasticity Branch

RTOP 505-63-50

Research Objective: The objectives of the Benchmark Models Program are to provide test data for evaluating new capabilities of computational aeroelasticity codes, increase physical understanding of unsteady flow phenomena, and provide test data for developing empirical design methods where computational methods need further development.

Approach: The Benchmark Models Program is a Structural Dynamics Division research effort involving the Configuration Aeroelasticity Branch, the Unsteady Aerodynamics Branch, and the Aeroservoelasticity Branch. Critical aeroelastic conditions needing test data for evaluation involve dynamic, mixed-flow phenomena at off-design flight conditions near envelope boundaries. The primary approach is to test instrumented well-defined dynamic models up to unstable flight conditions while recording unsteady pressures, dynamic loads, and quantitative flow visualizations. Planned areas of testing for this multi-year program include measurements of conventional transonic flutter, limit-cycle oscillation flutter, non-classical flutter, the effects of vortex flows on flutter, and burst-vortex induced buffeting. Transonic aeroelastic instabilities are of a particular interest due to their complicated flow conditions involving shocks and separated flows.

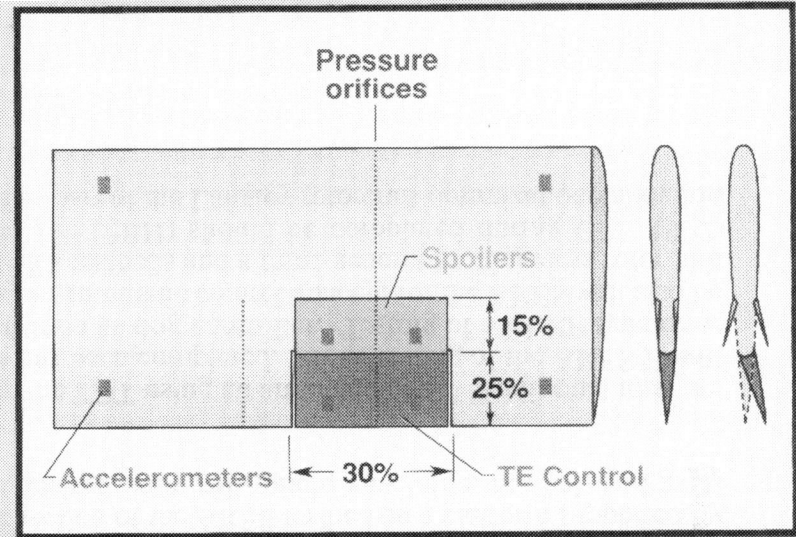
Status/Plans: The design and fabrication of four instrumented rigid rectangular wing models has been completed. These rigid models are to be flutter tested on a flexible mount system with pitch and plunge degrees of freedom providing a well-defined dynamic system. The first model with a NACA0012 airfoil successfully completed its second tunnel test entry in Feb.'91 with data reduction and formal documentation underway. The second model in this series has a supercritical airfoil designated SC(2)-0414. This Benchmark Supercritical Wing model has been fabricated, instrumented, is installed in the TDT, and is ready for testing during the first quarter of FY '92. A third model in this series is being fabricated with a 64A010 airfoil. All three models will be tested to flutter while recording two chords of unsteady pressure instrumentation totalling 80 transducers. Another rigid model has been fabricated for active controls testing. This model, scheduled for testing in June '92, is similar to the NACA0012 but with the addition of an active trailing edge control surface plus upper and lower surface spoilers. The purpose of this model is to quantitatively measure overall unsteady pressure effects and control surface effectiveness during flutter suppression. This model will also provide a simple well-defined controls testbed to explore new methods of flutter suppression such as actively controlled spoilers. A new initiative starting in FY '92 is to design and fabricate a flexible High Speed Civil Transport (HSCT) flutter model.

Figure 80 (a).

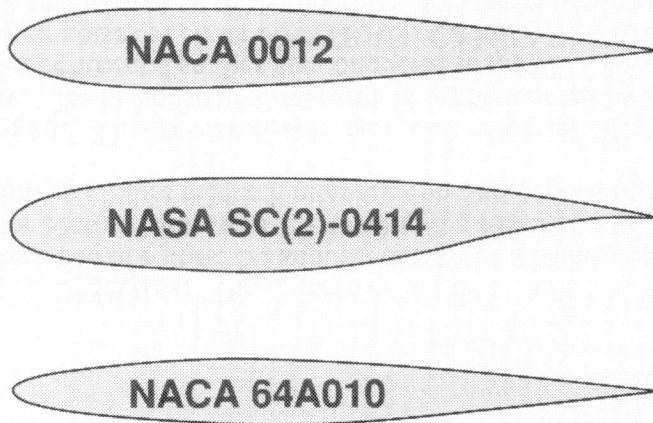
BENCHMARK MODELS



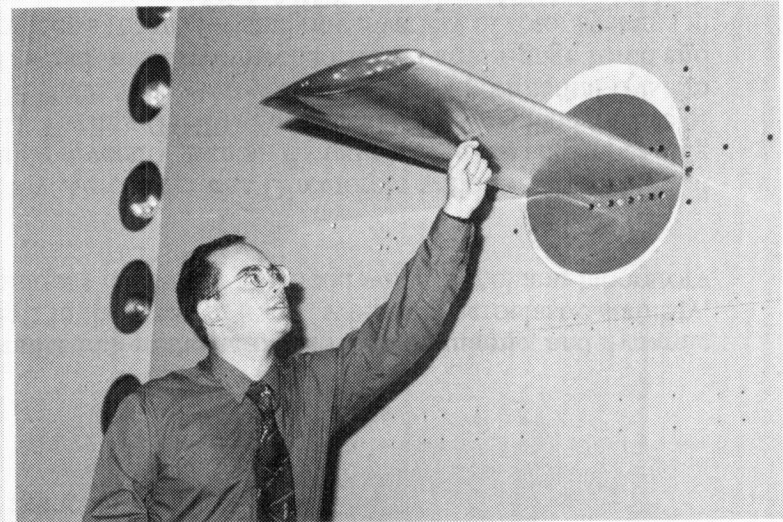
NACA 0012 Model



Active Controls Model



Family of Airfoils to Measure Unsteady Pressures at Flutter



SC(2)-0414 Model

Figure 80 (b).

ROTORCRAFT AEROELASTICITY

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Configuration Aeroelasticity Branch

RTOP 505-63-36

Research Objective: The objectives in this technical area are to (1) conduct research in the aeroelastic, aerodynamic, and dynamic characteristics of rotors; (2) support design of advanced performance rotorcraft in the areas of loads, vibration, aeroelastic stability, and rotor performance; and (3) develop the experimental and analytical techniques necessary to extend wind tunnel and laboratory capabilities to future research requirements and opportunities.

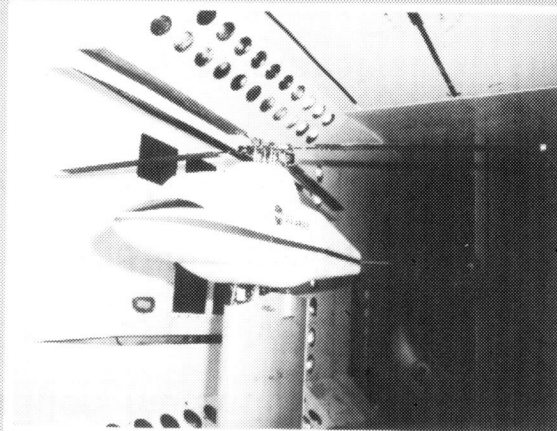
Approach: This research area is a joint effort of SDyD and the U.S. Army Aerostructures Directorate which is collocated at Langley. The in-house civil research is supplemented by industry contracts and university grants. As indicated in the accompanying figure, experimental studies are conducted in the TDT and the Helicopter Hover Facility (HHF). Analytical studies include the use of existing analyses such as NASTRAN, CAMRAD, CAMRAD - JA, and DYSCO. The Aeroelastic Rotor Experimental System (ARES) testbed is key to the conduct of experimental studies. This testbed, which has drive mechanisms, a strain-gage force and moment balance, and other equipment housed in a generic fuselage shape, provides a means for studying a variety of rotor systems in simulated forward flight in the TDT and in hover in the HHF. Two additional versions of the ARES are being developed which make it possible to better model the coupling of the rotor and the body. The ARES 1.5 design mounts the metric section of the existing ARES testbed on a static gimbal on "soft mount" to allow adjustment of the model fixed-system stiffness and damping characteristics in both pitch and roll. The ARES II design mounts the metric section of the ARES testbed on a platform supported by six computer controlled hydraulic actuators which are used to obtain the desired body roll, pitch, yaw, side, normal, and axial motion.

Status/Plans: An initial test of the ARES 1.5 testbed has been conducted in the TDT using an articulated hub. Additional tests are planned in the HHF using a hingeless hub. Fabrication of all ARES II parts has been completed. Initial testing of the ARES II will take place in the HHF following check-out of an in-house developed closed-loop analog controller. Testing of a BERP-type rotor will be conducted early in C.Y. 1992. During testing of the BERP-type rotor, an automatic control concept for the ARES will also be evaluated. Design work will continue for both a rotating balance for the ARES testbeds and a third-generation hingeless rotor hub (AHRO-III). Fabrication and initial testing of a Parametric Bearingless Hub (PBH) should be completed during C.Y. 1992. Fabrication will be initiated on the initial set of model optimized rotor blades as part of the Langley rotorcraft optimization/validation effort.

Figure 81 (a).

ROTORCRAFT AEROELASTICITY

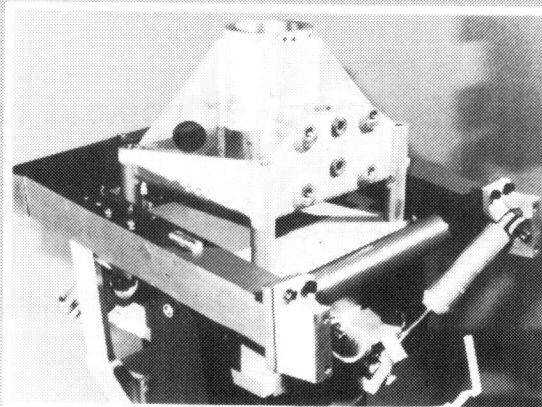
ARES TESTBED



RESEARCH AREAS

- Aeromechanical stability
- Rotor performance
- Vibration reduction
- Rotor acoustics

ARES II ACTIVE CONTROL SUPPORT



ADVANCED HINGELESS ROTOR

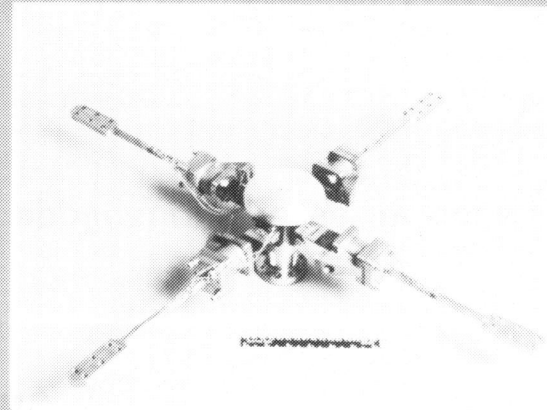


Figure 81 (b).

UNSTEADY AERODYNAMICS

F.Y. 1992 PLANS

- **CAP-TSD code application and support**
 - **Continue in-house and industry cooperative applications to verify code's range of accuracy**
 - **Continue to provide programming support**
- **Develop Euler and Navier-Stokes capabilities for steady/unsteady aerodynamic analysis**
 - **Grid generation methodology**
 - **Structured grid flow solvers**
 - **Unstructured grid flow solvers**
 - **Turbulence modeling**
- **Development of aeroelastic analysis methods for vortex dominated and buffeting flows**
 - **Coupled Navier-Stokes/structural dynamics procedure**
 - **Initial code validation studies**

Figure 82.

AEROSERVOELASTICITY

F.Y. 1992 PLANS

- **Design advanced control concepts for the benchmark controls model**
- **Integrate aeroelasticity and ASE into multidisciplinary design**
- **Investigate adaptive materials for dynamic response controllers**
- **Evaluate adaptive materials for controlling composite panel flutter**
- **Integrate nonlinear aerodynamics into ASE methods**
- **Enhance aeroservoothermoelastic procedures for NASP application**
- **Develop simulation laboratory to assess ASE in near-real time**
- **Apply MFT to aircraft with nonlinear control system**

MULTIRATE FLUTTER SUPPRESSION SYSTEM FOR THE BENCHMARK CONTROLS MODEL

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University of Washington

Vivek Mukhopadhyay
Aeroservoelasticity Branch

RTOP 505-63-50

Research Objectives: The objectives of this research are: 1) to develop a methodology for designing and analyzing robust multirate digital control laws; and 2) to demonstrate the benefits of multirate control by applying this methodology to the design of a multirate flutter suppression system for the Benchmark Controls Model Wing.

Approach: The multirate design methodology will utilize a computer algorithm previously developed at the University of Washington. This algorithm can synthesize low-order multirate compensators with independent sampling/update rates for each compensator input, output, or state. To improve the robustness of the multirate control laws synthesized by this algorithm, the algorithm will be modified to account for multiple plant conditions. This modification will allow synthesis of a multirate compensator which stabilizes the plant for a known set of plant perturbations. The robustness of this design will be analyzed by transforming the closed-loop multirate system into an equivalent single-rate system and applying an extension of μ analysis. Initially, a multirate flutter suppression system will be designed for analytical models of the Benchmark Active Controls Model Wing at six different flight conditions. The final design will be demonstrated by performing wind-tunnel tests.

Status/Plans: Several continuous-time flutter suppression systems have been designed for the analytical models of the Benchmark Controls Model Wing. These control laws were designed using *Sandy*, a computer program for synthesizing optimum, low-order, continuous-time control laws. The *Sandy* designs provide insight into appropriate sample rates for the multirate designs, and serve as a baseline for comparison with the multirate control laws. A preliminary multirate flutter suppression control law was designed, based on the continuous-time *Sandy* designs. In this control law, the accelerometer inputs from the wing and the output to the trailing-edge control surface actuator are sampled/updated at 200 Hz while the dynamics of the digital control law are updated at two different rates. The direct feed through terms in the control law are updated at 200 Hz, while the slower compensator dynamics are updated at 25 Hz. Updating the compensator dynamics at the slower rate reduces the computational load on the digital processor. In the future, other multirate control laws will be developed to study the effects of sampling rates on the performance and robustness of the flutter suppression system. In addition, multifunction control systems will be considered for demonstrating this technology. For example, preliminary designs of flutter suppression and gust load alleviation systems each being sampled at different rates will be obtained.

Figure 84 (a).

MULTI-RATE FLUTTER SUPPRESSION SYSTEM FOR THE BENCHMARK CONTROLS MODEL

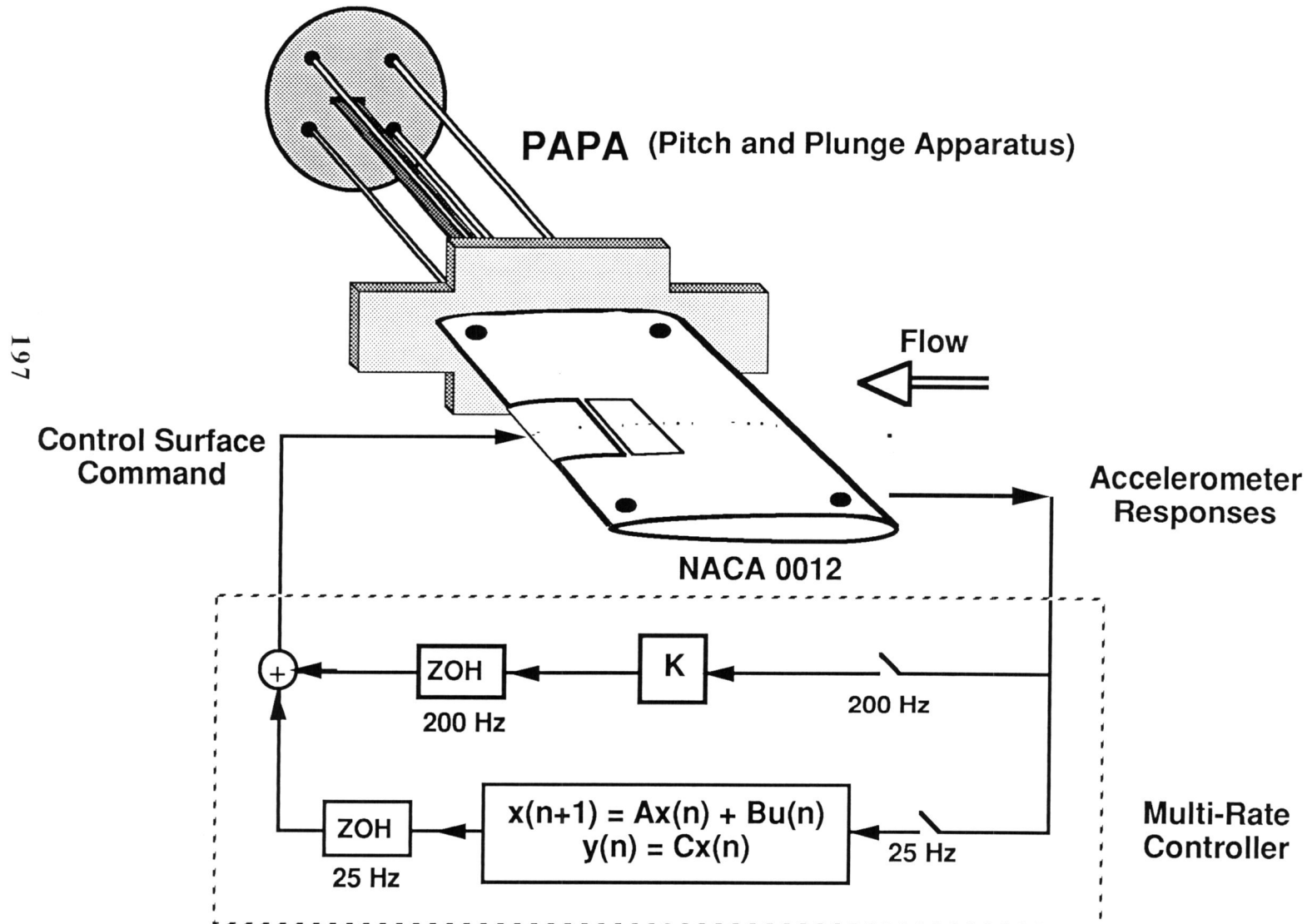


Figure 84 (b).

ANISOTROPIC COMPOSITE PANEL FLUTTER SUPPRESSION USING ADAPTIVE MATERIALS

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Purdue University

Robert C. Scott
Aeroservoelasticity Branch

RTOP 505-63-50

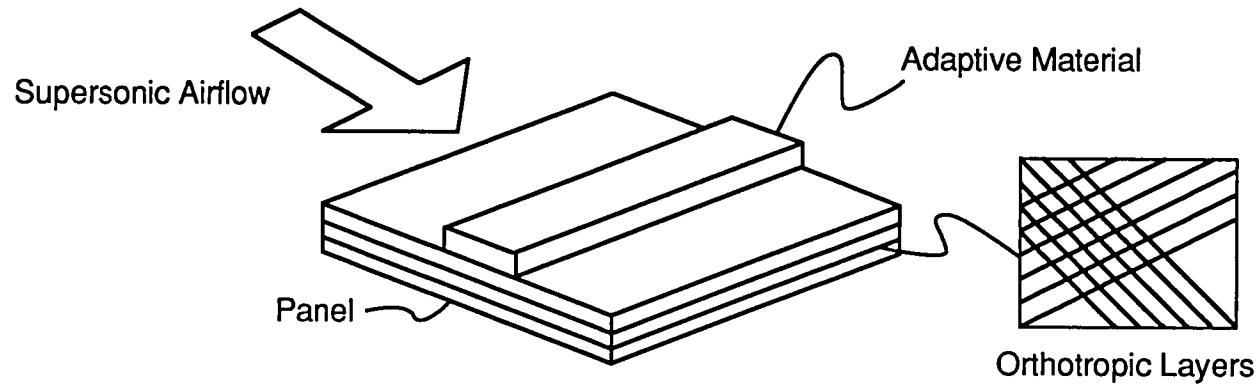
Research Objective: The objective of this activity is to investigate how adaptive materials (piezoelectric and shape memory materials) can be used to control undesirable aeroelastic instabilities in anisotropic composite panels. While the use of adaptive materials in isotropic panels has previously been investigated, the many design possibilities associated with composite panels combined with adaptive materials may offer lighter weight designs.

Approach: This is an analytical investigation to define the use of two types of adaptive materials for controlling panel flutter in anisotropic composite panels. The upper portion of the figure depicts a generic analytical model which will be used in this study. This model has been constructed such that parametric studies can be conducted, including variations of panel geometry, composite lay-ups and ply orientations, and actuator materials and locations. The three flutter suppression schemes to be considered are conventional, passive control, and active control. The lower left figure shows the conventional approach. Here, the panel stiffness is enhanced by increasing panel thickness, adding stiffeners, or aeroelastically tailoring the panel to increase its flutter speed. The center figure shows a passive control scheme in which shape memory or piezoelectric materials are used in a passive (on/off) manner to increase panel stiffness. Inputting a single finite temperature change to the shape memory material or a constant voltage to the piezoelectric actuator will provide a constant strain on the panel and thereby increase its stiffness. This change in stiffness has the effect of increasing panel flutter speeds due to increased separation of the frequencies of the critical elastic modes. In the third scheme, shown in the lower right, the adaptive materials will be actively controlled. Active control involves inputting a variable voltage to dynamically change the strain applied to the panel. Because of the low bandwidth of shape memory materials, only piezoelectrics will be considered here. Passive and active control schemes represent increased levels of complexity over conventional flutter suppression methods, and they must therefore be significantly lighter in order to justify their use.

Status/Plans: The flutter characteristics of the uncontrolled panels have been analyzed, and parametric studies of conventional panel flutter control methods has been initiated. Parametric studies with passively and actively controlled models will follow. Finally, the results of these studies will be analyzed and the capabilities of the conventional, passive, and active schemes will be compared in order to evaluate both the feasibility and the practicality of using adaptive materials for controlling panel flutter.

Figure 85 (a).

ANISOTROPIC COMPOSITE PANEL FLUTTER SUPPRESSION USING ADAPTIVE MATERIALS



Flutter Prevention Techniques

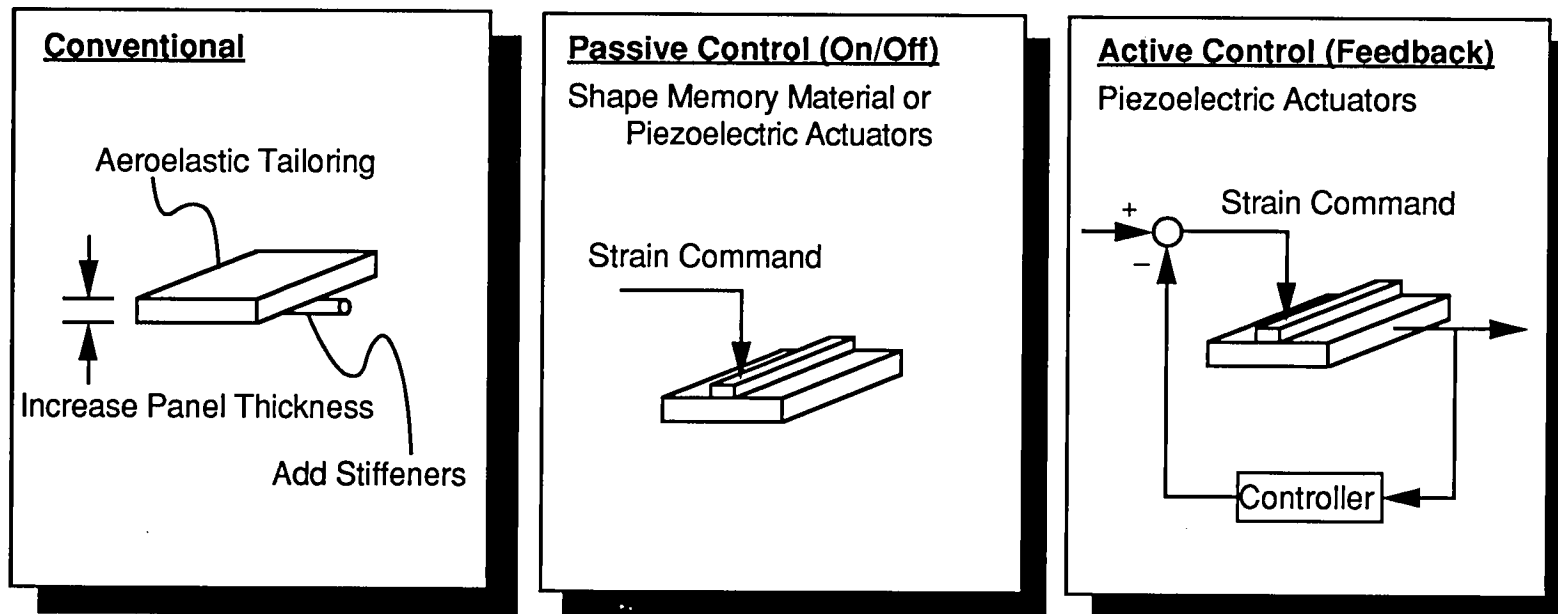


Figure 85 (b).

DEVELOPMENT OF A COMPUTATIONAL AEROSERVOELASTICITY METHODOLOGY

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Aeroservoelasticity Branch

RTOP 505-63-50

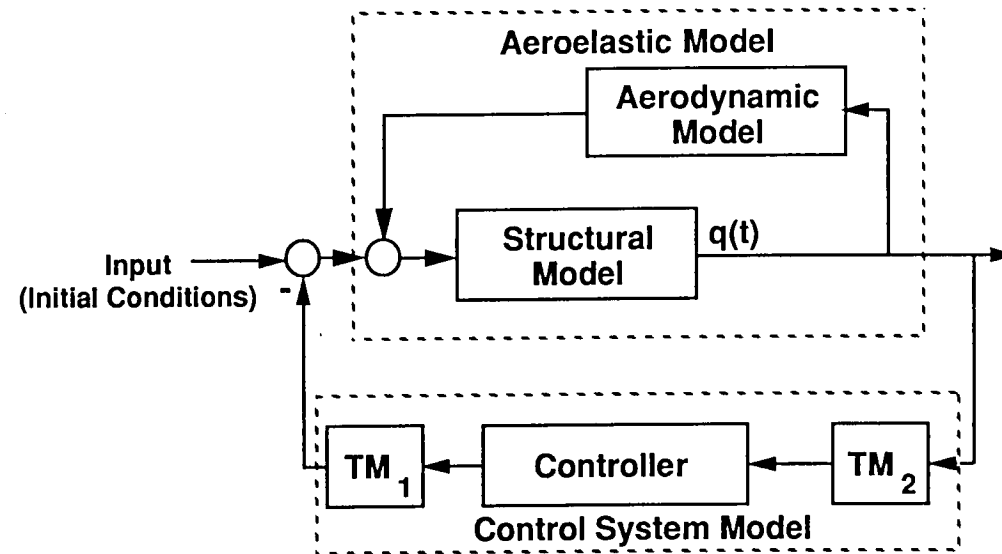
Research Objective: The objective of this research is to develop an efficient methodology for using nonlinear, time domain, unsteady aerodynamics in analyzing and designing active control systems capable of improving the aircraft's aeroelastic response at transonic speeds where significant aerodynamic nonlinearities are known to dominate the flow field.

Approach: Transient aerodynamic response information on a flexible aircraft for a specific set of configuration and flight condition parameters can be obtained from available computational unsteady aerodynamic/aeroelastic codes. Using a parameter identification algorithm (Eigensystem Realization Algorithm), a state-space aeroelastic model of the aircraft can be developed using the analytical aerodynamic response data. The state-space aeroelastic equations of motion can then be used to accurately and efficiently evaluate the aircraft's frequency and damping characteristics and, therefore, its open-loop stability. Given an active control system concept, it would then be possible to predict the closed-loop behavior of the aircraft using the state equations. In addition, an active control system can be designed using the state-space model and available advanced multi-input/multi-output design procedures without repeated execution of costly computational aerodynamic codes. To meet the project objective, it will be necessary to develop transformation matrices, TM_i , that relate control system parameters to the aeroservoelastic system's generalized coordinates, $q(t)$. In addition, it will be necessary that multiple aeroelastic state-space equations of motion be identified for various configuration (control surface static angles, angle of attack, etc) and flight condition variations (Mach number, dynamic pressure, etc) to assure that the control law design is sufficiently robust to account for the nonlinear effects expected at transonic speeds.

Status/Plans: Currently, the system identification algorithm is being evaluated using existing transient responses generated during an analytical evaluation of the National Transonic Facility's model sting. After completing this evaluation, the computational aeroservoelasticity methodology will be developed and demonstrated using linear and weakly nonlinear transient aerodynamic responses for a generic wing planform having a single trailing edge control surface.

Figure 86 (a).

DEVELOPMENT OF A COMPUTATIONAL AEROSERVOELASTICITY METHODOLOGY



METHODOLOGY

- Use Eigensystem Realization Algorithm (ERA) to Identify State-Space Model of Coupled Aerodynamic and Structural Model from CFD Transient Responses
- Use State-Space Model for Accurate and Efficient Evaluation of Aeroelastic System's Open-Loop Stability Characteristics
- Demonstrate Aeroservoelastic Analysis and Control Law Design in Time-Domain Using Linear/Weakly Nonlinear Transient Aerodynamic Responses
- Develop Transformation Matrices Relating Generalized Coordinates to Controller Input/Output Parameters

Figure 86 (b).

DIGITAL CONTROLLER/REAL-TIME SIMULATOR TO SUPPORT RESEARCH OF ACTIVE CONTROL TECHNOLOGY

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Sandra M. McGraw
Lockheed Engineering and Sciences Co.

RTOP 505-63-50

Research Objective: The objective of this project is to develop a digital controller/real-time simulator research tool for the purposes of: (1) supporting the design of control laws for actively controlled aeroelastic wind-tunnel models; (2) providing a simulation testbed for assessing state-of-the-art control law design methodologies; and (3) determining the functionality of the digital controller. The real-time simulator must have the flexibility to simulate different wind-tunnel models with different types of active controls quickly and easily.

Approach: The accompanying figure illustrates the approach that will be taken in this project. The two shaded regions on the left side of the figure represent the real-time simulator and the digital controller. The real-time simulator is comprised of two computers, a graphics display computer for visualizing model motion and the simulation computer for representing the ASE equations of motion. The arrows indicate the flow of information between computers. Communication between the digital control computer and the simulation computer occurs over analog lines through interface units with appropriate analog-to-digital (A/D) and digital-to-analog (D/A) conversions performed within the respective computers. The schematic on the upper right corner of the figure depicts a scene from the graphics display computer. The text describes the features of each of the three computers in the digital controller/real-time simulator overall system. Starting at the bottom and working up, the digital control computer computes actuator commands for multi-function, multi-rate, multi-input/multi-output digital control laws and saves data for control law analysis and performance evaluation. Its inputs are the sensor outputs (accelerations, rates, and loads) from the simulation computer. The simulation computer integrates the equations of motion and computes elastic deformations, control-surface deflections, sensor outputs and loads. Its inputs are the actuator commands output from the digital control computer. The graphics display computer provides a real-time visual display of the deforming wind-tunnel model. Its inputs are the deflections from the simulation computer.

Status/Plans: Again, starting with the digital control computer at the bottom of the figure and working up, the digital control computer will be a modified version of the digital controller used in the NASA/Rockwell Active Flexible Wing Program. Hardware is on hand; modifications to the software will be made to accommodate multi-rate control laws. This component of the overall system is 80% complete. The simulation computer will be a SUN SPARCstation. Hardware is also on hand; software is being designed. This component of the overall system is 30% complete. The graphics display computer will be an IRIS graphics computer. Hardware is also on hand; software is being designed. This component of the overall system is 10% complete. Future applications of this digital control/real-time simulation capability include the Benchmark Models Program, a rigid rectangular wing model with a NACA 0012 airfoil mounted on a Pitch and Plunge Apparatus (PAPA), depicted in the figure, and the MIT Strain Actuated Adaptive Structures Program using piezoelectric structural controllers. As aeroservoelastic models are developed for these two programs, corresponding simulation models will be implemented in the real-time simulator, digital control laws will be implemented in the digital controller, and the functionality of the digital controller will be tested using the simulation testbed.

Figure 87 (a).

DIGITAL CONTROLLER/REAL-TIME SIMULATOR TO SUPPORT RESEARCH OF ACTIVE CONTROL TECHNOLOGY

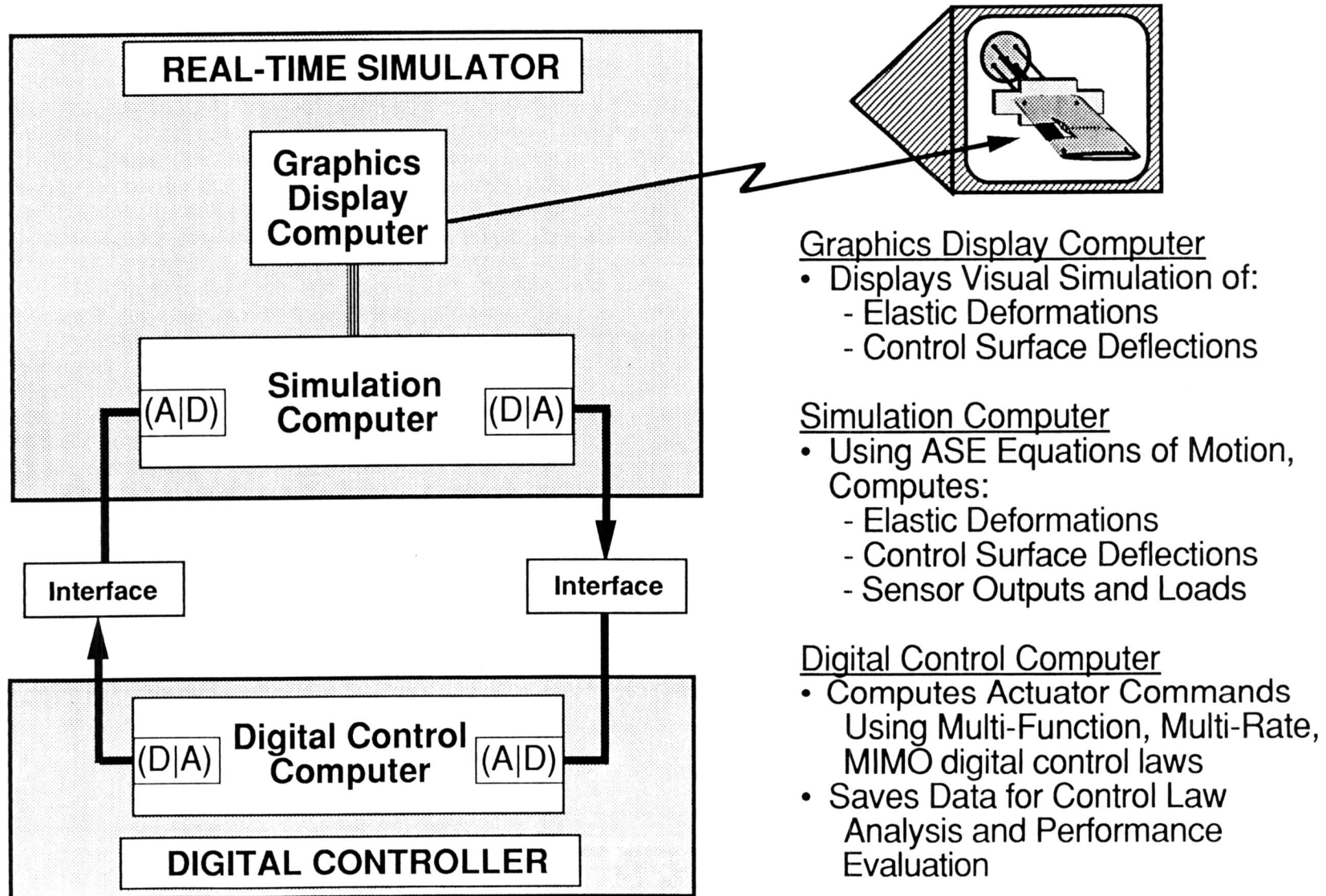


Figure 87 (b).

INVESTIGATE THE PROBABILITY ASPECTS OF MATCHED-FILTER BASED METHODS OF GUST LOAD PREDICTION

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Anthony S. Pototzky
Lockheed Engineering and Sciences Corporation

RTOP 505-63-50

Research Objective: Gust load analysis methods for nonlinear aircraft fall into two general categories which describe the type of input employed: deterministic and stochastic. The objective of this activity is to investigate the relationship between the matched-filter (deterministic) method and several stochastic-simulation methods.

Approach: The approach is to perform the matched-filter method and the stochastic-simulation methods on a simplified nonlinear aircraft model and then to compare the results. The outcome of these comparisons may then lead to theoretical and analytical studies which may help define the manner in which the methods are related to each other.

Status/Plans: The accompanying figure illustrates an initial comparison. The upper left box illustrates the analysis procedure for the matched-filter method. Here a constrained optimization algorithm starts with an initial excitation shape, then alters the shape, but not its energy, to maximize a particular load. With this optimized excitation shape, the corresponding gust and load time histories can be obtained. The lower left box illustrates the procedure employed for one of the stochastic-simulation methods. Here white noise is used to excite the system and a resulting gust profile time history and load time history are obtained. To compare the optimized results from the matched-filter method with "average" results from the stochastic simulation, the following procedure was used. Twelve 1000-second simulations were performed and the resulting load time histories were searched for "points in time" where a peak load was within a specified (high amplitude-comparable to the peak loads from the matched filter method) range. In this manner, eight peak loads from the twelve simulations were found within the specified range. Next, seven seconds of the corresponding excitation waveform (beginning seven seconds before each of the eight peak loads) were stored on a file. These eight excitation waveforms then were "lined up in time" so that each began at a relative time of zero and each ended seven seconds later. At each point in time the eight excitation waveforms were averaged, producing an averaged extracted excitation waveform which was then used to excite the gust filter, the output of which then excited the nonlinear model, producing a load time history. The three plots on the left contain comparisons of the averaged extracted results, just described, with the optimized results from the matched-filter method. It can be seen that the time histories obtained using stochastic simulations are very similar to those obtained from the matched-filter method and points to a relationship between the two methods. Additional comparisons between the matched-filter method and other stochastic-simulation methods are planned to further investigate the relationship between these methods.

INVESTIGATE THE RELATIONSHIP OF THE MATCHED-FILTER METHOD METHOD WITH SEVERAL STOCHASTIC-SIMULATION METHODS OF GUST LOAD PREDICTION

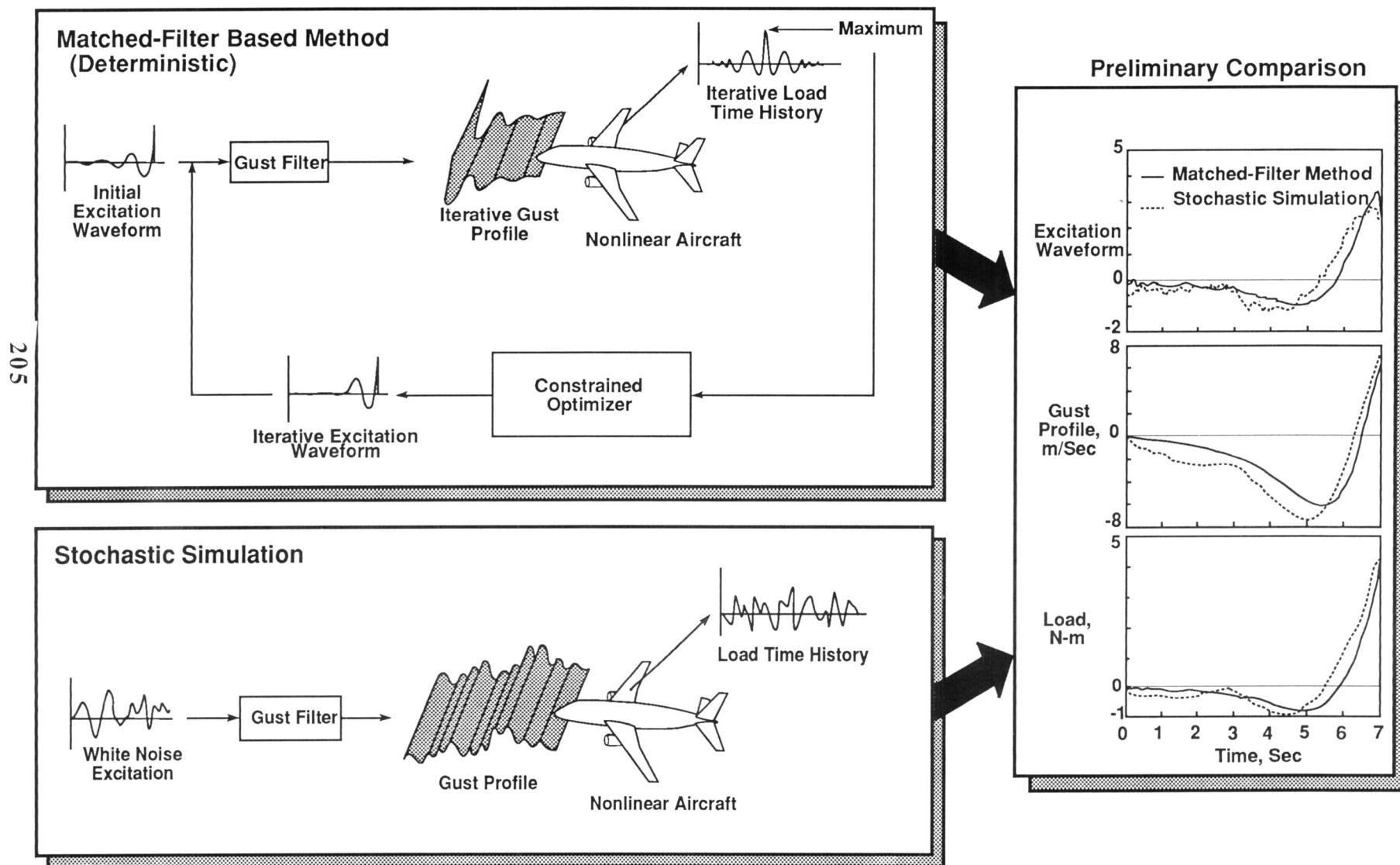


Figure 88 (b).

LANDING AND IMPACT DYNAMICS

F.Y. 1992 PLANS

- **Initiate task assignment contract for innovative composite structures test specimens**
- **Complete fabrication of composite subfloor concept for Lear Fan full-scale test specimen**
- **Complete evaluation of MSC/DYNA code for crash dynamics analyses**
- **Complete initial strength scaling studies with composites under compressive loads to define failure mechanisms**
- **Initiate grant study for optimizing composite frames for crash loads**
- **Complete static/dynamic tests to determine floor location effects on composite fuselage frame crash responses**
- **Continue development of computationally efficient algorithms for composite structural analysis**
- **Initiate study of coherent, crushable fuselage frame concepts**

LANDING AND IMPACT DYNAMICS

F.Y. 1992 PLANS

- **Initiate in-house research on smart orifice active control landing gear for F-106 aircraft**
- **Award grant to study electrorheological fluids for active control landing gear applications**
- **Award task assignment control to develop active control landing gear analysis tools**
- **Initiate analytical study on runway friction characteristics**
- **Complete minor CofF on ALDF valve body and additional high pressure water pump**
- **Develop second-order sensitivity derivatives for tire design and analysis**
- **Complete rolling tire footprint force measurements under START Program**
- **Complete smooth runway testing of START Program**

SPACECRAFT DYNAMICS

F.Y. 1992 PLANS

- **Controls-Structures Interaction**
 - **Validate integrated design of the Phase-One Evolutionary Model**
 - **Install multi-axis gimbals payloads and reconfigure hardware to achieve Phase-Two Model configuration**
 - **Bring online new real-time control computers**
- **Mission Dynamics**
 - **Validate component mode synthesis methods using existing DSMT analysis and test data**
 - **Initiate scale model redesign studies to reflect Space Station PIT truss concept**
- **Base Research and Technology**
 - **Develop online system identification methods for use in adaptive control**
 - **Begin in-house testing of seven degrees-of-freedom flexible manipulator test article**

INTERDISCIPLINARY RESEARCH F.Y. 1992 PLANS

- **Support**
 - **High-Speed Aircraft Integration Research (HiSAIR)**
 - **Rotorcraft design integration**
 - **Controls-Structure Integration**
- **Initiate**
 - **Configuration optimization in HiSAIR**
 - **Data preparation for experimental validation of optimal rotor blades**
 - **Incorporation of probabilistic methods in optimization**
- **Complete**
 - **Large space structure optimization for minimum weight**
 - **Mach 3 HiSAIR optimization**
 - **Integrated optimization of rotor blades including structures, structural dynamics, and aerodynamics**

Figure 91.

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